“Control Plane Extensions and Standardization”

ANNEX 1 TO

“Midterm Report On DICONET Exploitation And Dissemination Plans Including Contribution To Standards”

D7.2

‘DICONET_D7.2_Annex1_WP7_Huawei_1July09_V1.0_R’

Version: 1.0

Last Update: 1/7/2009 5:23:00 PM

Distribution Level: {PU}

The DICONET Project Consortium groups the following Organizations:

Partner Name	Short name	Country
JCP-Consult	JCP	FR
Research and Education Laboratory in Information Technologies	AIT	GR
Center of REsearch And Telecommunication Experimentations for NETworked communities	Create-NET	IT
Groupe des Ecoles des Telecommunications	ENST	FR
Huawei Technologies Deutschland GmbH	Huawei	DE
Interdisciplinair Instituut voor Breedband Technologie, VZW	IBBT	BE
Research Academic Computer Technology Institute	CTI	GR
University of Essex	UEssex	UK
Universitat Politècnica de Catalunya	UPC	SP
ADVA AG Optical Networking	ADVA	DE
Deutsche Telekom AG	DTAG	DE
Alcatel-Lucent France	ALF	FR
ECI Telecom	ECI	IL

Abstract:

This document surveys the current status of standardization activities related to optical control plane at the following forums: the International Telecommunications Union (ITU-T), the Internet Engineering Task Force (IETF), and the Optical Internetworking Forum (OIF). This document also provides an overview of the standards activity in optical monitoring, one of focuses of DICONET project. The aim of the survey is to provide inputs for the standards to be implemented or taken into consideration in the relevant WPs of DICONET. In particular, protocol extensions for physical information have been implemented based on IETF standards/drafts. A draft on protocol extensions for physical impairments supported by DICONET has been submitted to IETF.

"The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 216338"

Document Identity

Title:	Control Plane Extensions and Standardization (T7.2)
Subject:	Management, rules & procedures
Number:	
File name:	DICONET_D7.2_Annex1_WP7_Huawei_1July09_V1.0_R
Registration Date:	Tuesday, June 16, 2009
Last Update:	Wednesday, July 01, 2009

Revision History

No.	Version	Edition	Author(s)	Date
1	0	1	Yabin Ye, Thierry Zami, Uri Mahlab, 1. Chava Vijaya Saradhi	
	Comments:	Initial Release		
2	0			
	Comments:			
3	0			
	Comments:			
4	0	4		
	Comments:			
5	0			
	Comments:			
6				
	Comments:			
7				
	Comments:			
8				
	Comments:			
9				
	Comments:			
10				
	Comments:			
11				
	Comments:			
12				
	Comments:			
13				
	Comments:			
14				
	Comments:			
15				
	Comments:			

Table of Contents

List of Acronyms

ASE = Amplified Spontaneous Emission
ASON = Automatic Switched Optical Networks
ASTN = Automatic Switched Transport Networks
BER = Bit Error Rate
CCAMP = Common Control and Measurement Plane
CI = Characteristic Information
DCF = Dispersion Compensation Fiber
DGE = Dynamic Gain Equalizer
E-NNI = External network-to-network interface
FMEA = Failure Mode and Effect Analysis
FSC = Fiber or Port-Switch Capable
FWM = Four-Wave Mixing
GMPLS = Generalized Multi-Protocol Label Switching
IA-RWA = Impairment-Aware Routing and Wavelength Assignment
IEC = International Electrotechnical Commission
IETF = Internet Engineering Task Force
ITU-T = International Telecommunications Union
IV = Impairment Validation
L2SC = Layer-2 Switch Capable
LCD = Liquid Crystal Devices
LI = Linear Impairments
LMP = Link Management Protocol
LSC = Lambda Switch Capable
LSP = Label Switch Path
LSR = Label Switch Router
MEMS = Micro Electro Mechanical System
MPLS = Multi-Protocol Label Switching
NLI = Non-Linear Impairments
NMS = Network Management System
NNI = Network-to-Network Interfaces
OA = Optical Amplifier
OIF = Optical Internetworking Forum
QoS = Quality of Service
OSNR = Optical Signal-to-Noise Ratio
OSPF-TE = Open Shortest Path First with TE extensions
OTN = Optical Transport Network
OTS = Optical Transport System
OXC = Optical Cross-Connects
PCE = Path Computation Element
PCEP = Path Computation Element Protocol
PMD = Polarization Mode Dispersion
PMDC = Polarization Mode Dispersion Compensation
PSC = Packet Switching Capable
ROADM = Reconfigurable Optical Add/Drop Multiplexer
RSVP-TE = Resource reSerVation Protocol with TE extensions
RWA = Routing and Wavelength Assignment
SC = Switched Connection
SCN = Signaling Communications Network
SDH = Synchronous Digital Hierarchy
SML = Service management layer
SONET = Synchronous optical networking
SPC = Soft Permanent Connection
SPM = Self-Phase Modulation
SRS = Stimulated Raman Scattering
STM = Synchronous Transport Module
TE = Traffic Engineering

TBT	=	Technical Barriers to Trade
TDM	=	Time-Division Multiplex
UNI	=	User to Network Interfaces
WA	=	Wavelength Assignment
WDM	=	Wavelength Division Multiplex
WSON	=	Wavelength Switched Optical Network
WTO	=	World Trade Organization
XPM	=	Cross-Phase Modulation

1. Introduction

Transparent optical networks are beneficiating from the increasing bit-rate transmission capacity per wavelength with today with 40 Gbit/s and soon 100 Gbit/s and more, associated with the increasing number of wavelengths per optical interface and combined with new advances in terms of control functions based on Generalized Multi-Protocol Label Switching (GMPLS) control plane architecture and Path Computing Element functions extensions.

The first half of the document reports the network control and management contributions related to Wavelength Switched Optical Network (WSON) considering the advances at the following forums: the International Telecommunications Union (ITU-T), the Internet Engineering Task Force (IETF), and the Optical Internetworking Forum (OIF). The standardization contributions and the positions of the standard bodies remain subtle especially between these three standardization organizations ITU-T, IETF and OIF. The ITU-T usually takes a top-down approach by listing the requirements, working on the architecture components and then sometimes developing on the specifications of the network protocols. The IETF specification process is more centered on the specifications of the protocol engines and some of their related design while it is still referencing the requirements produced by ITU-T. Finally OIF is much related to the ITU-T requirements with the objectives to align the different protocol design and producing implementation agreements and promoting interoperability tests. The objective of the document is to provide a status on standard contributions related or even impacting the research activities involved in the DICONET project. The deliverable starts reporting the architecture recommendations delivered by ITU-T on Automatic Switched Optical Networks (ASON) and related optical connection services then it continues on the contributions produced by IETF on the specifications of the framework of WSON for PCE and GMPLS extensions. A draft proposal submitted to the IETF Common Control and Measurement Plane (CCAMP) working group from DICONET partners is also summarized here. Finally the OIF contributions are provided with a special focus on the optical network references points: user to network interfaces (UNI) and network-to-network interfaces (NNI) in regards with wavelength connection service deliveries.

Traditional TDM single-channel communication systems have been relayed on the electrical layer to provide the required performance monitoring. Performance parameters such as errored-second and severely-errored-second have been embedded in the SDH overhead and measure the network performance. 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 access to the electrical layer is not available. Moreover, the analog nature of the optical network, the increasing channel counts, the longer distance traveled, and the higher amplifier output power leads to an increasing influence of linear and non-linear distortions, which makes system commissioning an increasingly complex task. These challenges call for employment of optical monitoring throughout the network that monitors the most critical optical parameters. The ability to improve the end-to-end monitoring with distributed optical monitoring 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 optical monitoring.

The second half of the document provides overview of the standards activity in optical monitoring, one of focuses of DICONET project. The aim of this survey is to provide some inputs for the standards to be implemented or taken into consideration in the relevant WPs of

DICONET. In this document we made a survey of the ITU-T standard body [44][45] and the IEC86C standard.

2. Control plane standardization

2.1 Control plane standardization in ITU-T (ASON)

The generic functional architecture of transport networks is recommended by ITU-T [27] independently of specific optical switching technologies. This ITU-T recommendation can be referenced for several optical switching technologies by other ITU-T recommendation and OIF specifications (see section 2.3) including, SONET/SDH, G.709 or wavelength technologies and their IETF label switching specifications [18], [15] and [17] respectively.

The generic functional architecture G.805 was the basis to describe the requirements for automatic switched transport networks (ASTN) [26]. The ASTN requirements listed in G.807 were the basis for the developments of the architecture of automatically switched optical network G.8080 (ASON architecture) [25]. Although the recommendations of the ASON architecture rely on specific optical switching technologies such as listed previously, the ASON architecture is described from a high level of abstraction of the different functional components and described the protocol interactions between these components.

The three basic architecture units within ASON networks are nodes, links and sub-networks. The two formers are quite straightforward and match the physical optical network entities and are usually described in any network architectures.

The ASON sub-network is specified as an arbitrary set of network equipments or recursively as sub-networks. An ASON network can consider each sub-network that it contains as a virtual node from which each sub-network appears as a single virtual node with external links. This architectural concept usually presented as sub-network opacity improves the scalability of the control information (for the routing and signaling information as presented in section 2.2) because the detailed connectivity topology of the sub-networks is controlled hierarchically at different levels. This simplification is generally used to mask the interoperability issues due to legacy control within a sub-network, especially when a set of optical cross-connects (OXC) or reconfigurable optical add/drop multiplexer (ROADM) do not integrate recent development of GMPLS based controlled functions [31].

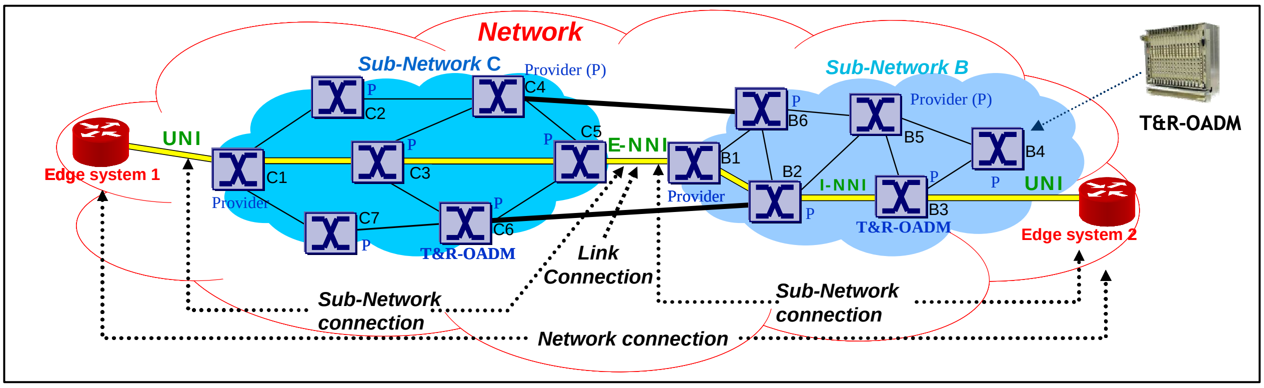

Figure 1: ASON network: links, nodes, sub-networks, connections and reference points

The sub-networks are actually built from well-established legacy networks such as SONET/SDH rings and the ASON architecture has been developed to integrate traditional transport network technologies with the new mesh optical networks as described in [32] where new end-to-end protection and full-mesh restoration configurations as analyzed in [33] are needed to be supported across different network topologies utilizing traffic engineering from the client networks through the user-to-network interfaces (UNI) and/or between two different sub-networks having or dynamic control capabilities through the external network-to-network interface (E-NNI).

For example the optical node equipments within the sub-network C in the Figure 1 may be legacy nodes that do not integrate any dynamic control capabilities while the sub-network B can be composed with Tunable & Reconfigurable - OADM nodes with GMPLS controller. The routing and signaling functions enable dynamic provisioning within the sub-network B. By representing sub-network C (on the left) as an abstract node, the node controllers of sub-network B can provision dynamically a wavelength connection for serving the connection services between the edge system 1 and edge system 2 according the QoS requirements such as bandwidth and latency within the sub-network B. The wavelength connection provisioning within sub-network B is performed independently of how the wavelength connection is established within sub-network C. The establishment of the wavelength connections within sub-network C is processed in such a way that the node C5 (entry point of sub-network C) signals the right level of QoS parameters towards the node B1. A possible scenario is that the optical resource reservation is performed statically through the network management systems (NSM) and the nodes B1 and C5 are responsible for stitching the sessions associated of the two wavelength connections signaled.

An important concept provided by ASON architecture is the separation of *call* and *connection* in order to provision network services and its maintenance. The *call* is an architecture entity defining an end-to-end relationship between the UNI clients, this entity is specified in ASON and the signaling extension defined in [20]. A *call* states the level of services required such as bandwidth, QoS (latency, jitter) and availability and is characterized by a calling and called party. The call entity allows applying defined policies and security to ensure that the egress node (i.e. the receiver) is satisfied with the wavelength connection services provided by the optical networks. The call entity is exposed to the network service management layer (SML) and consequently it is not associated to the provisioning or signaling of any network equipments to carry the client data traffic.

The routing and provisioning/signaling of the optical network resources for the *connection* entities as recommended by ASON within the transport network are associated together to transport data from one ingress client node to one egress client node. The ASON recommendations put new requirements on the network control functions [30] that were analyzed and assessed in [29] and [28] respectively.

Each connection is established over a network (as illustrated on Figure 1) and is structured with different parts: (i) between the client node (UNI-C) and the provider-edge node (UNI-N), (ii) across a sub-network, (iii) between sub-networks through E-NNI. Each connection is established between UNI-capable nodes and/or NNI-capable nodes and realizes the services expressed in the call.

2.2 Control plane standardization in IETF (GMPLS/PCE)

IETF is developing a standardized control plane for use in a Wavelength Switched Optical Network (WSON). This section gives an overview of the standardization protocol architecture and components developed so far by the IETF for WSON.

The IETF CCAMP working group is the design authority for all extensions to the GMPLS family of protocols. CCAMP participants have identified cases where they believe it would be helpful to consider optical impairments for the control plane operation of a WSON. The purpose of this work is to determine suitable end-to-end paths that meet the service objectives in optical networks (i.e. to perform constrained path computation).

This gives rise to four distinct deployment scenarios [1]:

1. No concern for impairments or lambda continuity because there is sufficient margin in all impairments. (Original GMPLS)
2. No concern for impairments (again because there is sufficient margin), but lambda continuity is important. (The RWA problem)
3. Networks in which it is necessary to consider impairments, but there is sufficient margin such that approximate impairment estimation (using "simple" computation of the accumulation) could be used and still have a high probability that the optical path would be viable. Also adding or removing an optical signal on the path will not render any of the existing signals in the network non viable. One form of non-viability is the occurrence of transients in existing links.
4. Networks in which in order to determine whether a path is viable it is necessary to perform a full computation of the accumulation of impairments including the impact on existing paths.

2.2.1 Original GMPLS

Generalized Multi-Protocol Label Switching (GMPLS) [14] extends the MPLS architecture specified in RFC3031 from supporting only packet interfaces and switching (Packet Switching Capable - PSC) to also include support for four new classes of node interfaces and switching as (i) Layer-2 Switch Capable (L2SC), (ii) Time-Division Multiplex (TDM), (iii) Lambda Switch Capable (LSC) and (iv) Fiber or Port-Switch Capable (FSC). A functional description of the extensions to connection signaling needed to support new classes of interfaces and switching is provided in [14].

In MPLS, a label is an arbitrary tag for data packet that is used as an index to look-up into a Label Forwarding Information Base for determining the next hop for the labeled data. The Label Forwarding Information Base contains a mapping of an interface associated to an incoming label to another interface associated to an outgoing label. In MPLS controlled network labels are not directly coupled with a network resource (e.g. a router interface).

In GMPLS controlled networks, the physical resources are identified by GMPLS labels (e.g. TDM, Lambda or Fiber labels) and are exactly the switchable quantities. For example in optical networks, wavelength can be switched at each OXC. The GMPLS label control functions bring new challenges and constraints that are not existing in packet switched networks. GMPLS label values may need to have a semantic end-to-end rather than just locally at each Label Switched Router (LSR) as for example identifying the frequency values of the wavelengths.

In GMPLS the significance of a label is private between two adjacent LSRs, and the two LSRs have to control the label in a coordinated way. Specification developments on labeling G.709 optical data units are encoded with specific values [15] such that G.709 frames can be deduced from its label values. In the same approach TDM labels are given a special encoding so that the signaled optical timeslot can be automatically deduced [18].

Recent works at CCAMP are addressing specifications to the use of GMPLS with a new generation of Lambda Switch Capable (LSC) equipment. Technologies such as ROADM and OXC switch at the wavelength level. Consequently, the wavelength frequency is an important information that is necessary to set up a wavelength-based LSP appropriately. But for fiber switching the meaning of the label is left as a concern of the network operator for configuring its value or discovery and negotiation through the link management protocol (LMP) as specified in [35].

2.2.2 Routing and Wavelength Assignment

The RWA problem means path computation and wavelength assignment in WSON when there are limited cross-connection capabilities, limited wavelength availability or limited wavelength conversion capabilities. These limited information are clarified in [31] which focuses on the unique properties of links, switches and path selection constraints that occur in WSONs and provides a framework for applying GMPLS and the Path Computation Element (PCE) architecture to the control of WSONs. In particular [31] provides control plane models for key wavelength switched optical network subsystems and processes. The subsystems include wavelength division multiplexed links, tunable laser transmitters, ROADM and wavelength converters.

The alternative approach for RWA is to distribute the wavelength related limited information throughout the network. To do this there must be some mechanism [31] to distribute the information. The approach under consideration by CCAMP is to provide extensions to the Traffic Engineering routing protocols (OSPF-TE) [3] and signaling protocol (RSVP-TE) [4]. The approach under consideration by PCE is to define the procedures necessary and protocol extensions for PCE and Path Computation Element communication Protocol (PCEP) [5][16].

In order to make these potential approaches work, it is necessary for the nodes or path computation element to have a common understanding of mapping between labels and wavelength. Unlike the traditional label which only has meaning in the context of the link on which it is used. CCAMP defined a new label format [6] that has meaning in a global context. The wavelength label format is consistent with ITU-T’s definition of wavelength gird.

In order to make the above RWA potential approaches work, another problem that must be resolved is to derive a consistent encoding of the information distributed by the routing protocol or other potential protocol. CCAMP in [7] analyzed what information needs to be distributed and how to provide a protocol-independent encodings [8] for distribution of related limited information.

CCAMP in [4] provides extensions to Generalized Multi-Protocol Label Switching (GMPLS) signaling for control of WSON. In particular, extensions are given to characterize optical signal types via traffic parameters, permit simultaneous bi-directional wavelength assignment, and control the distributed wavelength assignment process. These extensions build on previous work for the control of G.709 based networks.

[3] from CCAMP partners describes OSPF routing protocols extensions to support WSON under the control of GMPLS. [5] from PCE Working Group partners provides application-specific requirements for the PCEP for the support of WSON.

2.2.3 Impairment Aware Routing and Wavelength Assignment

Long haul optical transmissions pose new requirements on GMPLS for handling possible physical impairments. Fundamentally, the optical layer is lowest in the transport hierarchy and hence is strongly impacted by the physical geography of the network. Consequently some IETF contributions such as [19] analyze the aspects of optical networks that impact routing and identify possible GMPLS based control function response for constraints such as wavelength continuity in a single domain, complications arising in more complex networks incorporating both all-optical and opaque architectures, and the impacts of diversity constraints.

To route connections in an all-optical network, it is usually assumed that all routes have adequate signal quality. This may be ensured by limiting all-optical networks to sub-networks of restricted size that are optically isolated from other parts of the optical layer by transponders. This approach is practical and has been applied to date, e.g., when determining the maximum length of an Optical Transport System (OTS). Network operational considerations like fault isolation also make limiting the size of domains of transparency interesting.

There are criteria for constraints domains of transparency in which not all wavelength routes have adequate signal quality. Bandwidth demands from client networks and maximum bit rates have rapidly increased to 10 Gb/s (e.g. STM-64/OC-192) and 40 Gb/s (STM-192/OC-768) and soon 100 Gb/s. As bit rates increase it is necessary to increase power, it makes impairments and nonlinearities more troublesome. From network provider interests, optical technology is advancing very rapidly, making ever-larger transparency domains possible. It is generally assumed that these observations will lead to the deployment of domains of transparency too important to ensure that all potential routes have adequate signal quality for all circuits [19]. It is capital to analyze the impacts of the various types of impairments in this environment.

As initially proposed [34], the non-linear effects like Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), Four-Wave Mixing (FWM) as well as Stimulated Raman Scattering (SRS) and Brillouin scattering could need to be examined in order to evaluate their impacts on the transmission quality. These optical impairments accumulate along the path (without 3R regeneration) traversed by the signal. They are influenced by the type of fiber used, the types and placement of various optical devices and the presence of other optical signals that may share a fiber segment along the signal's path. The degradation of the optical signals due to impairments can result in unacceptable bit error rates or even a complete failure to demodulate and/or detect the received signal. Therefore, path selection in any WSON requires consideration of optical impairments so that the signal will be propagated from the network ingress point to the egress point with an acceptable signal quality.

There is a thing need to be noted is that optical impairment is not an IETF's area but ITU-T's area of study. To work better on path computation in WSON with consideration of optical impairment, a joint meeting between Q.6/15 and members of IETF's CCAMP working group clarified the deployment scenarios which is described at the beginning of section 2.2. For the scenario 3, G.680 might help to calculate path viability. For scenario 4, there was agreement between members of IETF's CCAMP WG and Q.6/15 that current state of the art technology does not provide a model to calculate viable paths in this scenario. A technical break-through would be required to achieve this [1].

So in the current IETF area of study, only scenario 1, 2, and 3 are involved. Based on the existing ITU-T standards covering optical characteristics (impairments) and the knowledge of how the impact of impairments may be estimated along a path, [9] from CCAMP partners provides a framework for impairment aware path computation and establishment utilizing

GMPLS protocols and the PCE architecture. As in the impairment free case covered in [31], a number of different control plane architectural options are described.

In impairment aware routing and wavelength assignment (IA-RWA), [9] defined three general classes of processes to be considered: Routing (R), Wavelength Assignment (WA), and Impairment Validation (estimation) (IV). This leads to several possible architectural models as follows:

A. Combined R, WA, and IV

From the point of view of optimality, the "best" IA-RWA solutions can be achieved if the path computation entity (PCE) can conceptually/algorithmically combine the processes of routing, wavelength assignment and impairment validation. Such a combination can take place if the PCE is given: (a) the impairment-free WSON network information as discussed in [31] and (b) impairment information to validate potential paths.

B. Separated Routing, WA, or IV

Separating the processes of R, WA and/or IV can reduce the need for sharing of different types of information used in path computation. In addition, since some impairment information may not be shared and this may lead to the need of separating IV from RWA. If IV needs to be done at a high level of precision it may be advantageous to offload this computation to a specialized server.

The following conceptual architectures belong to this general category:

- R+WA+IV – Separated R, WA, and IV.
- R + (WA & IV) - R is separated from a combined WA and IV process. Note that IV is typically wavelength dependent hence combining WA with IV can lead to high efficiency.
- (RWA)+IV - Combined RWA with a separated IV process.

Note that the IV process may come before or after the RWA processes. If RWA comes first then IV is just rendering a yes/no decision on the selected path and wavelength. If IV comes first it would need to furnish a list of possible (valid with respect to impairments) routes and wavelengths to the RWA processes.

C. Distributed WA and/or IV

This approach allows distributed computation of impairment effects and avoids the need of distributing impairment characteristics of network elements and links via route protocols or by other means. An example of such approach is given in [10] and utilizes enhancements to RSVP signaling to carry accumulated impairment related information. A distributed impairment validation for a prescribed network path requires that the effects of impairments can be calculated by approximate models with cumulative quality measures such as those in G.680. If distributed WA is being done at the same time as distributed IV then we may need to accumulate impairment related information for all wavelengths that could be used. This is somewhat winnowed down as potential wavelengths are discovered to be in use, but could be a significant burden for lightly loaded high channel count networks.

In the non-impairment RWA situation it was shown that a consistent encoding of the information needed to be defined for distribution by the routing protocol or other potential protocol. Similarly, [11] analyzed what information needs to be distributed and how to provide a protocol-independent encodings [12] for distribution of related optical impairment information.

To deal with various impairments encountered by optical paths, various impairment compensation technologies have been developed. For example, chromatic dispersion may be compensated by dispersion compensation fiber (DCF) or an electronic or optical compensation device at the transmitter or the receiver of the signal. Insertion of 3R repeaters or an optical amplifier at an optical path's transient node may also be regarded as a compensation effort. Although some compensation technologies offer fixed or limited compensation ranges against impairments, compensation technologies with wide and dynamically tunable compensation ranges have been developing. Such compensation technologies are especially suited for a dynamically established optical path because impairment compensation by them can be automatically adjusted as adequate corresponding to a requested path's impairments. Based upon these observations, [13] discusses how compensation control for tunable compensation technologies is handled within the WSON framework and requirements of impairment compensation control to the Control Plane.

2.2.4 DICONET IETF draft

The key innovation of DICONET is the development of a dynamic network planning tool residing in the core network nodes that incorporates real-time measurements of optical layer performance into IA-RWA algorithms and is integrated into a unified control plane. So based on this project objective, we focus on Impairment Aware WSON area in IETF.

A draft supported by DICONET project has been submitted to IETF CCAMP [9]. This draft discusses how the definition and characterization of optical fiber, devices, subsystems, and network elements contained in various ITU-T recommendations can be combined with GMPLS control plane protocols and mechanisms to support Impairment Aware Routing and Wavelength Assignment (IA-RWA) in optical networks.

2.2.5 Protocol extensions for physical information based on IETF

In order to design and implement the protocol extension approaches which both RSVP-TE and OSPF-TE are extended to carry physical layer impairments and wavelength availability information, respectively, we have gone through several relevant IETF drafts. The following are the main IETF drafts that we have followed in order for the proposed design solution and extensions to be more close to the activities in standardization bodies. Following IETF drafts are very critical, as our designed solution need to be compliant or almost close to the real-world scenarios. We have extended RSVP-TE path messages to carry physical layer information following the drafts [36][37][15][38][9][39][40][41]. RESV message is extended following the draft [9]. The problem of message fragmentation is solved using the drafts [40][41]. For the development of new mechanisms for extension of RSV-TE behavior to include Q-Check protocol, we have referred drafts[7]. For the extension of OSPF-TE with wavelength availability information we referred the draft [42]. The main contributions after following the drafts as mentioned above are as follows:

Standard RSVP-TE signalling messages are extended to carry information required to compute Q-factor and evaluate optical feasibility. The following information is required in the *PATH* message: ***1) requested service/traffic parameters:*** a) service type such as encoding type, payload type, etc., b) service QoS such as bandwidth, etc., c) extended service optical parameters such as transponder type, etc. ***2) signalled path parameters:*** d) path parameters/QoS such as hop number, minimum latency, etc., e) extended path optical parameters (e.g., OSNR, power, CD, PMD, PMD, and cross-talk). ***3) path resources and status:*** f) label-set, g) path sections description such as fiber type, length, input power, input

CD, etc., h) path sections active lightpaths such as active LSP *IDs*, transponder type, wavelength, bit-rate, etc.

The standard *GENERALIZED_LABEL_REQUEST* [36] and *TSPEC/FLOW_SPEC* [36][37][15] objects support encoding of (a) and (b). Standard one pass with advertising (OPWA) information is carried in the *ADSPEC* object [37] encodes (d). Standard *LABEL_SET* object [36] with *GENERALIZED_LABEL* encodes (f). The encoding of (c), (e), (g), and (h) requires extensions to the standard *PATH* message and are encoded in *LSP_REQUIRED_ATTRIBUTES* object [38][9][39]. Note that *PATH* message size increases due to the addition of path section information and affected channel information at each hop. The *PATH* message size can easily exceed the maximum transfer unit (MTU) and may lead to message fragmentation. Large MTU values[40] or jumbo frames [41] may also be exceeded in worst case scenarios. A possible solution to *message fragmentation* is described in [9], which splits *PATH* message into multiple messages.

The information is required in *RESV* message is: selected channel information such as, channel identifier, and link physical properties able to evaluate all LIs and NLIs (e.g., CD, Q-factor, etc. We encoded this information in *LSP_REQUIRED_ATTRIBUTES* object [38][9][39]. The standard RSVP-TE behavior has also been extended to trigger *Q_CHK_REQ* to check if the set of new light disrupts any active lightpaths in the network.

To manage the Q-factor of affected lightpaths we have defined a new protocol with following three messages: 1) *Q_CHK_REQ* is defined to check if Q-factor of affected lightpath and new lightpath (in case of changes in network status) destination nodes. It contains affected and affecting LSP *IDs*, etc., 2) *Q_CHK_RESP* is defined to get response from the affected lightpaths destination node and it only contains whether *Q_CHK_REQ* is successful or not. 3) *Q_CHK_REL* is defined to update the Q-factor of affected channels destination node and it contains same information as *Q_CHK_REQs*. For the implementation this protocol we have explored several possible options such as COPS, SOAP, XML RPC, etc. Finally, we have selected the two best possible options [42][43].

2.3 Control plane standardization in OIF

The Optical Internetworking Forum (OIF) specifies the content and the operations of the ASON reference points namely User-to-Network interfaces (UNI), and the Network-to-Network Interfaces (NNI) and specifically on the External-NNI (E-NNI) as illustrated on Figure 1 and with a focus on the signaling message exchanges as the exchanges of routing information is subject to administrative policies in the case of multiple network operators.

The first implementation agreement on the signaling messages to be exchanged between a client node controller and a server node controller was OIF UNI 1.0 published on October 2001 [21] then a second release was produced OIF UNI 1.0 release 2 two year later and the a second version was published through OIF UNI 2.0 for carrier grade Ethernet connections [22].

UNI 1.0 scope is to define the set of connection services, the signaling protocols used to invoke these services, the control channels used to transport signaling messages and the auto-discovery procedures that aid signaling, all are implemented by client network at UNI-C node and by the transport network at the UNI-N node. The document [21] is based on RSVP-TE protocol as an early implementation based on reusing existing signaling protocols and auto-discovery mechanisms. Only signaling for connection service request invocation is within the scope of UNI 1.0. Routing, reach-ability and address resolution protocols are outside the scope. Also, the UNI 1.0 specification focuses on TDM connection services as SONET/SDH.

The UNI 2.0 [22] extends the previous version by considering Optical Transport Networks (i.e., G.709 and [15]), and carrier grade Ethernet connection services.

The specification of E-NNI signaling abstract messages, attributes, and flows to establish end-to-end dynamic connections across multiple control domains is provided in [23] and it is based on the RSVP-TE protocols. This specification applies to SDH/SONET, G.709 (OTN ODUk), and Ethernet connection services in support of [22]. E-NNI 2.0 describes the support of Soft Permanent Connection (SPC) and Switched Connection (SC) services over the E-NNI, associated ASON architecture.

The ASON architecture supports both single- and multi-layer networks. Multi-layer scenarios include network elements that support more than a single layer, a layer network that supports virtual concatenation and its server layers, transport services that exist where the client layer has no resources in the sub-network except at its edges, etc.

For example, at the edge of a multi-layer transport network, a network element may support client layer networks that are not directly supported in the core of a multilayer transport network. The client CI (Characteristic Information, [G.805]) could be adapted, possibly multiple times, onto server layer connections. Multilayer support refers to the ability to handle the adaptation of one CI into another CI.

E-NNI 2.0 [23] is limited to operations on a single layer network at a time and there is no support for Ethernet Switching at the E-NNI 2.0 interfaces.

Routing, reach-ability, and address resolution protocols are not described [23] outside as well as specifications related to signaling communications network (SCN) design, auto-discovery, and policy as recommended in [26].

The first discussions on the routing functions of E-NNI 2.0 have started through an initial contribution [24]. The initial considerations are focused on extending OSPF-TE with multi-domain capabilities.

3. Optical monitoring standardization

3.1 Optical monitoring standardization in ITU-T

3.1.1 Classification of monitoring methods

The ITU-T distinguishes between several approaches for optical monitoring:

- Signal monitoring
- Equipment monitoring
- Embedded monitoring
- External monitoring devices.

3.1.1.1 Signal monitoring

Signal monitoring are non-intrusive measurements that allow in-service monitoring of the optical signal quality. A distinction between frequency- and time-domain measurement methods is made:

A. Time domain methods

The time domain monitoring methods analyses the behavior of the optical signal in the time domain. These methods are close to full BER measurement and are sensitive to both noise and distortion effects. Sampling oscilloscopes and Q-factor meters are representative of the time domain methods. The drawbacks of these methods are that they generally need optical demultiplexing, optical to electrical conversion and, in the case of sampling methods, synchronization to the bit rate.

B. Frequency (or wavelength) domain methods

Frequency/wavelength domain methods analyses 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 analyzer device. 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 drawback of the spectral methods is that they are averaging methods; Thus, by definition, do not sense the pulse distortion and are insensitive to all of the effects due to distortions.

3.1.1.2 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, laser temperature etc., 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 one assumes 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.

3.1.1.3 Embedded monitoring equipment

In this approach the monitoring equipment is an integral part of the system and its measurement results are reported directly to the network management (NMS). For cost reasons, embedded monitoring is usually limited to the most basic parameters such as optical power.

3.1.1.4 External monitoring equipment

External monitoring approach is based on test equipment that is temporarily employed to measure additional, more sophisticated performance parameters. This approach is usually employed during the network installation and/or in case of a failure or repair.

3.1.2 Optical monitoring parameters

The list of the optical parameters that can be measured using current technology in optical transmission systems is given below.
– Channel power;
– Total power;

– Optical Signal-to-Noise Ratio (OSNR);
– Channel wavelength;
– Q-factor.

3.1.3 Optical impairments

The main systems impairments at the optical layer that limit the capacity of the system to transport information:

- Attenuation
- Optical channel power changes due to gain variations
- Frequency (or wavelength) deviation from nominal
- Polarization Mode Dispersion (PMD) (1st and higher orders)
- Four-Wave Mixing (FWM)
- Amplified Spontaneous Emission (ASE) noise in OA
- Chromatic dispersion
- Chromatic dispersion slope
- Reflections
- Laser noise
- Inter-channel crosstalk
- Interferometric crosstalk
- Cross-Phase Modulation (XPM)
- Self-Phase Modulation (SPM)
- Stimulated Brillouin Scattering (SBS
- Stimulated Raman Scattering (SRS)

3.2 Optical monitoring standardization in IEC

3.2.1 Background about IEC

3.2.1.1 IEC Mission

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardization and as references when drafting international tenders and contracts. Through its members, the IEC promotes international cooperation on all questions of electrotechnical standardization and related matters, such as the assessment of conformity to standards, in the fields of electricity, electronics and related technologies. The IEC charter embraces all electrotechnologies including electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety and the environment.

3.2.1.2 IEC Objectives

The Commission's objectives are to:

- meet the requirements of the global market efficiently
- ensure primacy and maximum world-wide use of its standards and conformity assessment systems
- assess and improve the quality of products and services covered by its standards

- establish the conditions for the interoperability of complex systems
- increase the efficiency of industrial processes
- contribute to the improvement of human health and safety
- contribute to the protection of the environment.

3.2.1.3 IEC Standards

IEC's international standards facilitate world trade by removing technical barriers to trade, leading to new markets and economic growth. Put simply, a component or system manufactured to IEC standards and manufactured in country A can be sold and used in countries B through to Z.

IEC's standards are vital since they also represent the core of the World Trade Organization's Agreement on Technical Barriers to Trade (TBT), whose 100-plus central government members explicitly recognize that international standards play a critical role in improving industrial efficiency and developing world trade. The number of standardization bodies which have accepted the Code of Good Practice for the Preparation, Adoption and Application of Standards presented in Annex 3 to the WTO's TBT Agreement underlines the global importance and reach of this accord.

IEC standards provide industry and users with the framework for economies of design, greater product and service quality, more inter-operability, and better production and delivery efficiency. At the same time, IEC's standards also encourage an improved quality of life by contributing to safety, human health and the protection of the environment.

For more information please refer to http://www.iec.ch/

3.2.2 Review aspects of IEC86C

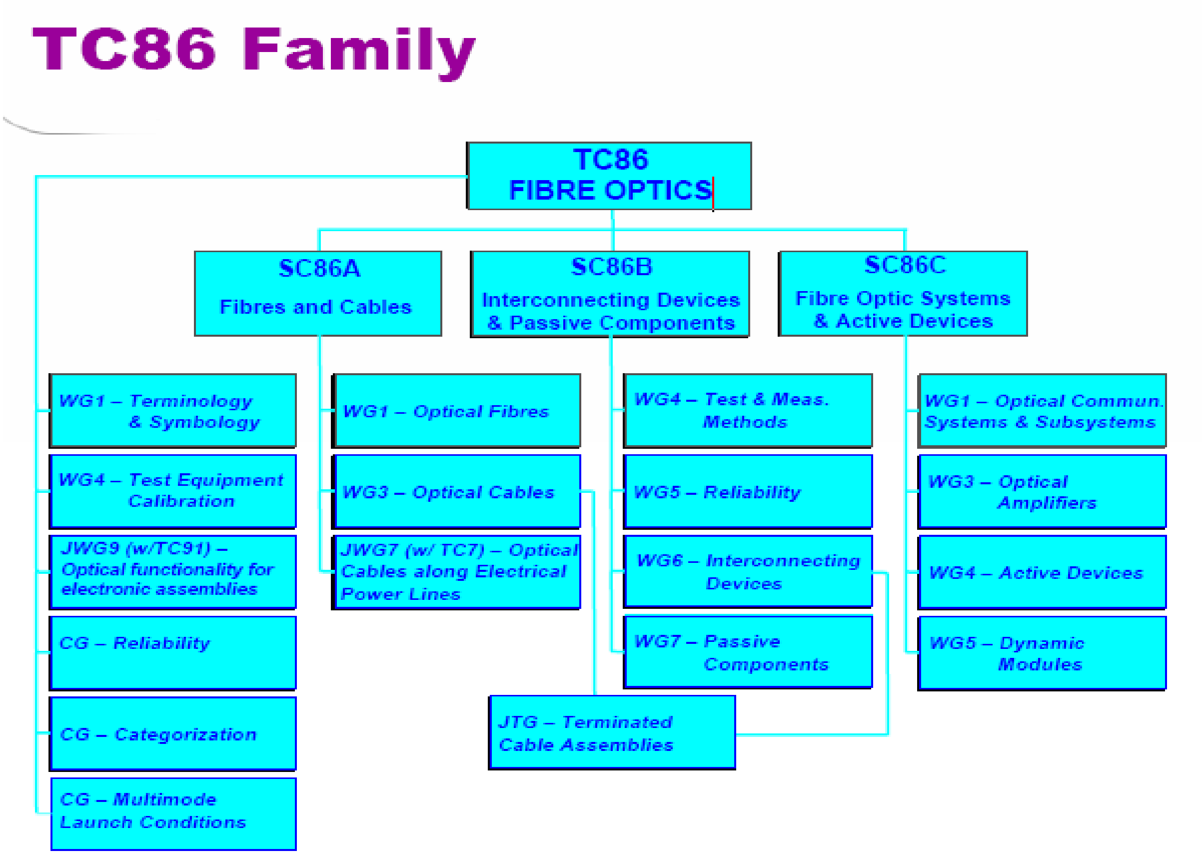

Fig. 2 IEC86C family

Fig.2 shows the IEC86C family. As we can see, IEC86C deals with 4 WPs:

WP1 about optical communication systems and subsystems

WP2 about optical amplifier

WP4 – about optical active devices

WP5 – about Dynamic modules

This section provides a brief summary the IEC recommendations for technical specifications or guidelines for optical issues as well as monitoring and its features. Several drafts deal with dynamic optical modules and are covered in 86C. The followed documents list covers several issues dealing with the standardization activity in optical dynamic module.

62343	Dynamic Modules Standards – General and Guidance
62342-1	Dynamic Modules – Performance Standards
62343-1-2	Performance Standards – Dynamic Chromatic Dispersion Compensator with Pigtails for Use in Controlled Environments (Category C)
62343-1-3	Performance Standards – Dynamic Gain Tilt Equalizer with Pigtails for Use in Controlled Environments (Category C)
62343-1-4	Performance Standards – Polarization-Mode Dispersion Compensator with Pigtails for Use in Controlled Environments (Category C)
62343-2	Dynamic Modules – Reliability Qualification
62343-3	Dynamic Modules – Performance Specification Templates
62343-3-1	Dynamic Channel Equalizers
62343-4	Dynamic Modules – Software and Hardware Interface Standards
62343-4-1	Dynamic Modules Standard – Hardware and Software Interfaces
62343-5	Dynamic Modules – Test Methods
62343-5-1	Dynamic Gain Equalizer – Response Time Measurement
62343-5-2	Dynamic Modules – Phase Ripple Measurement Method
62343-5-3	Dynamic Modules – Monitoring test of mechanical shock and vibration
62343-6-6	Dynamic Modules - Failure Mode Effect Analysis for Optical Units of Dynamic Modules

Not all of these documents deal with monitoring in optical modules, thus, we had focused below only on the relevant documents with activities that can contribute to DICONET.

Some draft provides inputs about PMD (Polarization Mode Dispersion) DGE (dynamic Gain Equalizer) and tunable module. PMD is a becoming a limit for today/future networks. The PMD is a phenomenon in which for polarized light, two modes are propagated through a single-mode fiber and become separated as they propagate. The separation at the output of the fiber is the DGD, resulting in a system impairment that varies also with state of polarization Monitoring PMD is extremely important for high bit rate networks. The document "PMD-DICONET.doc" discuses PMDC issue and was examined in WP3.2. This document deals with measurement techniques of various PMDC proposed by the equipment manufacturers. (The documents can be found also in D 3.2). The dynamic gains tilt equalization control has a great impact on networks functionality, reliability and optimization in both performance and economy aspects. A dynamic gain equalizer (DGE) in reconfigurable next generation WDM systems must have the capability of flattening any optical profile with irregular power levels.

The DGE module has the ability to control the attenuation profile and thus plays an important role in monitoring spectral response over wide dynamic range of desired band.

We have followed the IEC-86c standard which deals with tunable modules. Although the main contribution of this document is to analyze and propose measuring and investigating dynamic gain tilt equalizer Response time, these methods could be served for dynamic networks behavioral forecast (See 86c-62343-5-1).

The Document 62343-6-6 “Dynamic Modules - Failure Mode Effect Analysis for Optical Units of Dynamic Modules” can serves as an input to WP4.4 about “failure localization algorithm”. The following summary provides short overview about document 62343-6-6.

3.2.2.1 Consideration of types of dynamic modules

There are many types of dynamic modules; dynamic channel equalizer, tunable optical chromatic dispersion compensator, dynamic gain tilt equalizer, wavelength selective switch, wavelength blocker, optical performance monitor, optical switch, and so on. Main feature of dynamic modules is to control their performances during operation. In order to achieve their features, many kinds of control methods are used for dynamic modules; MEMS (micro electro mechanical system), stepping motor, electromagnet, thermo optics, magnet optics, electro optics, LCD (liquid crystal devices), and so on.

3.2.2.2 Typical failure points

A typical optical unit for dynamic module consists of different parts: optical element, outer packages, fibre pigtails, optical semiconductor chips, and joint points of these elements. These elements have their own failure mode, for example; break for pigtails, displacement for joint points, and so on. Moreover, these elements may have their acceleration factor of degradation; for example joint points fixed by adhesive are generally weak against high humidity, and so on. These failure mode analysis can be referred to FMEA for passive optical components (refer 62005-3).

There are special considerations for dynamic module. Here are some examples; When the hermetic sealing structure is used, it may be omitted damp heat test because it can generally prevent to enter humidity. When using MEMS, operating shock and vibration test are necessary because MEMS is sensitive against mechanical shock and vibration. When temperature control is used, temperature cycling test is recommended because temperature control functions generally produce thermal stress by temperature distribution of modules and temperature cycling test can accelerate thermal stress.

3.2.2.3 Failure modes and known failure mechanisms

For some dynamic modules, failure mode and effect analysis (FMEA) was carried out. Table 2 (In Appendix) shows known failure mechanisms, failure effects, failure modes, relevant tests and IEC test document number for dynamic modules. Relevant tests are listed with the failure effect and the dominant known failure mechanism. As other relevant tests or methods of failure mode excitation become known, these should also be added in a supplementary table and published.

4. References

[1] "Minutes of joint meeting between members of IETF's CCAMP WG and Q.6/15" ITU-T Q.6/15 WD6-38, March 2009.

[2] Fatai Zhang, G. Bernstein, Young Lee, Dan Li, Jianrui Han, "OSPF Extensions in Support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSONs)", work in progress: draft-zhang-ccamp-wson-routing-ospf-00.txt, March 2009.

[3] G. Bernstein, Sugang Xu, Y. Lee, Hiroaki Harai, D. King, "Signaling Extensions for Wavelength Switched Optical Networks", work in progress: draft-bernstein-ccamp-wson-signaling-03.txt, October 2008.

[4] Y. Lee, G. Bernstein, T. Takeda, T. Otani, "PCEP Requirements for WSON Routing and Wavelength Assignment", work in progress: draft-lee-pce-wson-routing-wavelength-04.txt, March 2009.

[5] T. Otani, H. Guo, K. Miyazaki, D. Caviglia, "Generalized Labels for G.694 Lambda-Switching Capable Label Switching Routers (LSR)", work in progress, draft-ietf-ccamp-gmpls-g-694-lambda-labels-04.txt, March 2009.

[6] Y. Lee, G. Bernstein, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", draft-bernstein-ccamp-wson-info-03.txt, March, 2009.

[7] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical networks", work in progress, draft-ietf-ccamp-rwa-wson-encode-01.txt, March 2009.

[8] G. Bernstein, Y. Lee, D. Li, G. Martinelli, "A Framework for the Control of Wavelength Switched Optical Networks (WSON) with Impairments", work in progress: draft-bernstein-ccamp-wson-impairments-05.txt, May 2008.

[9] G. Martinelli (ed.) and A. Zanardi (ed.), "GMPLS Signaling Extensions for Optical Impairment Aware Lightpath Setup", Work in Progress: draft-martinelli-ccamp-optical-imp-signaling-01.txt, February 2008.

[10] Y. Lee, G. Bernstein, "Information Model for Impaired Optical Path Validation", work in progress: draft-bernstein-wson-impairment-info-01.txt, February 2009.

[11] G. Bernstein, Y. Lee, "Information Encoding for Impaired Optical Path Validation", work in progress: draft-bernstein-wson-impairment-encode-00.txt, March 2009.

[12] S. Seno, "Requirement of Impairment Compensation Control in WSON", work in progress: draft-seno-ccamp-wson-impairment-compensate-cntl-00.txt, March 2009.

[13] Lou Berger, "Generalized Multi-Protocol Label Switching Signaling Functional Description", IETF RFC 3471, January 2003.

[14] Mannie E., "Generalized Multi-Protocol Label Architecture", RFC 3945, October 2004.

[15] Papadimitriou, D., "GMPLS Signaling Extensions for G.709 Optical Transport Networks Control", RFC 4328, January 2006.

[16] J.P. Vasseur and J.L. Le Roux, "Path Computation Element (PCE) Communication Protocol (PCEP)", IETF RFC 5440, March 2009.

[17] Tomohiro Otani, "Generalized Labels of Lambda-Switching Capable Label Switching Routers (LSR)", work in progress at IETF, draft-ietf-ccamp-gmpls-g-694-lambda-labels-04.txt, March 23, 2009.

[18] Mannie, E. & D. Papadimitriou, "GMPLS Extensions for Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Control", IETF RFC 4606, August 2006.

[19] Strand, J. & A. Chiu, “Impairments and Other Constraints on Optical Layer Routing”, RFC 4054, May 2005.

[20] Dimitri Papadimitriou and Adrian Farrel, “Generalized MPLS (GMPLS) RSVP-TE Signaling Extensions in Support of Calls”, IETF RFC 4974, August 2007

[21] “User Network Interface (UNI) 1.0 Signaling Specification”, The Optical Internetworking Forum (OIF), October 2001

[22] “User Network Interface (UNI) 2.0 Signaling Specification: Common Part”, The Optical Internetworking Forum (OIF), February 2008

[23] “OIF E-NNI Signaling Specification (OIF E-NNI 2.0)”, The Optical Internetworking Forum (OIF), working document (OIF2005.381.30), February 2009.

[24] “OIF E-NNI Routing 2.0 Implementation Agreement”, The Optical Internetworking Forum (OIF), draft document (OIF2007.379.01), November 2007

[25] “Architecture for the automatically switched optical network (ASON)”, ITU-T Recommendation G.8080/Y.1304, June 2006

[26] «Requirements for automatic switched transport networks (ASTN)”, ITU-T Recommendation G.807/Y.1302, July 2001.

[27] “Generic functional architecture of transport networks”, ITU-T Recommendation G.805, March 2000

[28] Dimitri Papadimitriou et al., “Evaluation of Existing Routing Protocols against Automatic Switched Optical Network (ASON) Routing Requirements”, IETF RFC 4139, October 2006

[29] Deborah Brungard et al., “Requirements for Generalized Multi-Protocol Label Switching (GMPLS) Routing for the Automatically Switched Optical Network (ASON) ”, IETF RFC4258, November 2005

[30] Dimitri Papadimitriou et al., “Requirements for Generalized MPLS (GMPLS) Signaling Usage and Extensions for Automatically Switched Optical Network (ASON)”, IETF RFC 4139, July 2005

[31] Young Lee et al., “Framework for GMPLS and PCE Control of Wavelength Switched Optical Networks (WSON)”, works in progress at IETF, draft-ietf-ccamp-rwa-wson-framework-02.txt, March 2009.

[32] Jean-Paul Faure, “From ROADM technology to TOADM technology: on the path towards optical restoration and fully flexible networks”, ECOC’2008.

[33] D. Verchere, B. Berde, O. Audouin, L. Daans, G. Grammel, J. Fernandez, J. Lobo, “Efficient Recovery Strategies for IP/MPLS over Optical Transport Networks”, ECOC’2006.

[34] D. Papadimitriou, J. P. Faure, O. Audouin, R. Appelman, “Non-linear Routing Impairments in Wavelength Switched Optical Networks”, IETF draft (deprecated), May 2001, http://tools.ietf.org/id/draft-papadimitriou-ipo-non-linear-routing-impairm-01.txt

[35] Andre Fredette et al., “Link Management Protocol (LMP) for Dense Wavelength Division Multiplexing (DWDM) Optical Line Systems”, IETF RFC 4209, October 2005

[36] L. Berger, “Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource reSerVation Protocol-Traffic Engineering (RSVP-TE) Extensions,” *RFC 3473*, Jan 2003.

[37] J. Wroclawski, “The Use of RSVP with IETF Integrated Services,” RFC2210, Sep 1997.

[38] A. Farrel *et al.*, “Encoding of Attributes for Multiprotocol Label Switching Label Switched Path Establishment Using Resource reSerVation Protocol-Traffic Engineering,” RFC 4420, Feb 2006.

[39] A. Farrel *et al.*, “Encoding of Attributes for Multiprotocol Label Switching Label Switched Path Establishment Using Resource reSerVation Protocol-Traffic Engineering,” *IETF draft*, May 2008.

[40] R. Atkinson *et al.*, “Default IP MTU for use over ATM AAL5,” *RFC 1626*, May 1994.

[41] J. Kaplan *et al.*, “Extended Ethernet Frame Size Support,” *IETF draft*, Nov 1999.

[42] http://www.w3.org/TR/soap/

[43] http://www.xmlrpc.com/

[44] “Optical Monitoring for DWDM systems”, ITU-T Recommendation G. 697, June. 2004

[45] “Guide on the use of the ITU-T SG15 Recommendations related to optical technology”, ITU-T Supplement 42, Feb. 2008

Appendix

Failure Mode Effect Analysis for Optical Units of Dynamic Modules

1. Scope

This technical report describes failure mode effect analysis for optical units of dynamic modules. FMEA is one of the effective and useful analysis methods in order to determine the reliability evaluation test items and conditions which are defined in reliability qualification document; 62343-2. In order to estimate the lifetime for a module, there is a typical procedure. First step: identify the dominant failure modes, second step: determine the acceleration tests according to these failure modes, third step: carry out the test, fourth step: estimate the acceleration factors, fifth step: calculate the lifetime of the dynamic module. IEC 61300-2 documents series defines environment and mechanical tests. This technical report describes the dominant failure mode for dynamic modules and relevant tests from IEC 61300-2 series.

2. Normative references

The following references documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61300, series: Fibre optic interconnecting devices and passive optical components- Basic tests and messurement procedures.

IEC 62005-3: Reliability of fibre optic interconnecting devices and passive optical components- Part 3: Relevant tests for evaluating failure modes and failure mechanisms for passive components.

IEC 62343-2: Dynamic modules- Part-2: Relialibility qualification.

IEC 61291-5-2: Reliability qualification for optical fibre amplifiers.

3. Consideration of types of dynamic modules

There are many types of dynamic modules; dynamic channel equalizer, tunable optical chromatic dispersion compensator, dynamic gain tilt equalizer, wavelength selective switch, wavelength blocker, optical performance monitor, optical switch, and so on. Main feature of dynamic modules is to control their performances during operation. In order to achieve their features, many kinds of control methods are used for dynamic modules; MEMS (micro electro mechanical system), stepping motor, electromagnet, thermo optics, magnet optics, electro optics, LCD (liquid crystal devices), and so on.

Table 1 shows the first guidance of categorization of dynamic modules to consider how to evaluate. For dynamic modules without electrical circuit board, they can be considered similar approach as passive optical components in order to evaluate. On the other hand, for dynamic modules with control circuit board, it is necessary to consider special notice. And there are mainly two types of internal design for dynamic modules; the first one is that it is easy to divide the constituting parts to consider the reliability, and the second one is not easy to divide. It is necessary to consider how to evaluate according to these structures.

Note: This document describes FMEA only for optical units for dynamic modules. It is necessary to evaluate whole dynamic modules including control circuit boards and firmware if used.

4. Typical failure points

Besides control circuit board and control or moving parts, a typical optical unit for dynamic module consists of different parts: optical element, outer packages, fibre pigtails, optical semiconductor chips, and joint points of these elements. These elements have their own failure mode, for example; break for pigtails, displacement for joint points, and so on. Moreover, these elements may have their acceleration factor of degradation; for example joint points fixed by adhesive are generally weak against high humidity, and so on. These failure mode analysis can be referred to FMEA for passive optical components (refer 62005-3).

There are special considerations for dynamic module. Here are some examples; When the hermetic sealing structure is used, it may be omitted damp heat test because it can generally prevent to enter humidity. When using MEMS, operating shock and vibration test are necessary because MEMS is sensitive against mechanical shock and vibration. When temperature control is used, temperature cycling test is recommended because temperature control functions generally produce thermal stress by temperature distribution of modules and temperature cycling test can accelerate thermal stress.

5. Failure modes and known failure mechanisms

For some dynamic modules, failure mode and effect analysis (FMEA) was carried out. Table 3 shows known failure mechanisms, failure effects, failure modes, relevant tests and IEC test document number for dynamic modules. If new technology and new dynamic modules become commercially available, they should be added to Table 2. Relevant tests are listed with the failure effect and the dominant known failure mechanism. As other relevant tests or methods of failure mode excitation become known, these should also be added in a supplementary table and published.

Table 1 – Categorization based on the structure how to evaluate

Electrical circuits		How to evaluate	Examples
Without electrical circuits	N.A.	As optical component	VOA, 1x2/2x2 optical switch, DGTE
With electrical circuit	Easy to divide optical and electrical unit	As optical and electrical units individually, and as integrated dynamic module	VOA, VOA-MUX, DCDC, DCE, Matrix switch, Channel monitor, performance monitor
	Hard to divide optical and electrical unit	To evaluate as integrated dynamic module	Wavelength blocker, wavelength selectable switch

Note 1. Constituting optical active and passive components shall comply reliability qualification requirement defined in 62572 series for active components and 62009-9 series for passive optical components, respectively.

In case to be hard to divide optical and electrical units, integrated module shall be tested (refer 62343-2).

Note 2. Electrical circuit board shall comply TC91 standard.

Note 3. Integrated dynamic module shall be tested 3 pieces for each test if constituting components are qualified (refer 62343-2).

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Variable optical attenuators	MEMS type	MEMS	Stacking the moving part	Uncontrollable	Mechanical stress Excess driving power	Shock (storage) Vibration (storage) Maximum absolute rating test (electrical) On/off driving test	61300-2-9 61300-2-1 Understudy Understudy
			Distortion of hinge/mirror	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Mechanical stress Thermal stress Excess driving power	Shock (storage) Vibration (storage) Shock and vibration (operating) Change of temperature Maximum absolute rating test On/off driving test	61300-2-9 61300-2-1 Understudy 61300-2-22 Understudy Understudy
			Reflectance of mirror changing	Insertion loss increase Attenuation change Return loss decrease PDL increase WDL increase	High humidity (non-hermetic sealed)	Damp heat	61300-2-19
		Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Dynamic range of attenuation decrease PDL increase WDL increase	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
		Pigtail	Fibre broken, micro-bending	Insertion loss increase No operation	Mechanical stress for pigtail	Fibre cable retention Optical fibre cable flexing	61300-2-4 61300-2-44
	Liquid crystal type	LCD	Degradation of LCD	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Thermal stress High humidity (non-hermetic sealed) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
			Electrical polarization of LCD	Uncontrollable	Excess driving power	Maximum absolute rating test On/off driving test	Understudy Understudy
			Freezing of LCD	Uncontrollable	Low temperature	Cold	61300-2-17
		Collimator	Same as MEMS type				
		Pigtail	Same as MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Variable optical attenuators	Magnet optic type	Magnet optic part	Dislocation of magnet, Faraday rotator and birefringent crystal	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
		Collimator					
		Pigtail	Same as MEMS type				
	Mechanical type	Moving part	Stacking the moving part	Uncontrollable	Mechanical stress High humidity (non-hermetic) Excess driving power	Shock (storage) Vibration (storage) Damp heat Maximum absolute rating test (electrical) On/off driving test	61300-2-9 61300-2-1 61300-2-19 Understudy Understudy
			Degradation of moving part	Driving power increase	Mechanical stress Thermal stress Excess driving power High humidity (non-hermetic sealed)	Shock (storage) Vibration (storage) Shock and vibration (operating) Change of temperature Maximum absolute rating test On/off driving test Damp heat	61300-2-9 61300-2-1 Understudy 61300-2-22 Understudy Understudy 61300-2-19
			Distortion of mirror	Insertion loss increase Return loss decrease Crosstalk increase PDL increase	Mechanical stress Thermal stress Excess driving power	Shock (storage) Vibration (storage) Change of temperature Maximum absolute rating test On/off driving test	61300-2-9 61300-2-1 61300-2-22 Understudy Understudy
			Reflectance of mirror changing	Insertion loss increase Attenuation change Return loss decrease PDL increase WDL increase	High humidity (non-hermetic sealed)	Damp heat	61300-2-19
		Collimator	Same as MEMS type				
		Pigtail	Same as MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Variable optical attenuators	Planar waveguide type (thermal optic effect)	Waveguide	Refractive index changing	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
			Electrode degradation	Dynamic range of attenuation decrease	High humidity (non-hermetic sealed and using adhesive) Excess driving power	Damp heat Maximum absolute rating test Diving test	61300-2-19 Understudy Understudy
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Thermal stress High humidity (non-hermetic sealed and using adhesive)	Change of temperature Damp heat	61300-2-22 61300-2-19
		Pigtail	Same as MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Optical switches	Mechanical type	Moving part	Stacking the moving part	Uncontrollable	Same as VOA mechanical type		
			Degradation of moving part	Driving power increase Switching time increase	Same as VOA mechanical type		
			Distortion of mirror	Insertion loss increase Return loss decrease Crosstalk increase PDL increase	Same as VOA mechanical type		
			Reflectance of mirror changing	Insertion loss increase Return loss decrease PDL increase WDL increase	Same as VOA mechanical type		
		Collimator	Same as VOA MEMS type	Insertion loss increase Crosstalk increase PDL increase WDL increase	Same as VOA mechanical type		
		Pigtail	Same as VOA MEMS type				
	Planar waveguide type (thermal optic effect)	Waveguide	Refractive index changing	Insertion loss increase Crosstalk increase Return loss decrease PDL increase	Same as VOA PLC TO type		
			Electrode degradation	Crosstalk increase	Same as VOA PLC TO type		
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Same as VOA PLC TO type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Optical switches	MEMS type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Insertion loss increase Crosstalk increase Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
			Reflectance of mirror changing	Insertion loss increase Crosstalk increase Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
		Collimator	Same as VOA MEMS type	Same as VOA MEMS type except; Crosstalk increase instead of Attenuation change	Same as VOA MEMS type		
		Pigtail	Same as VOA MEMS type				
	Electrical optics type (LN)	Waveguide	Refractive index changing	Insertion loss increase Crosstalk increase Driving voltage changing	Thermal stress Mechanical stress Excess driving power	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage) Maximum absolute rating test Diving test	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1 Understudy Understudy
			Electrode degradation	Crosstalk increase	Same as switch PLC TO (VOA PLC TO) type		
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Same as switch PLC TO (VOA PLC TO) type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Tunable filters (electrical control)	MEMS etalon type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Insertion loss increase Centre-wavelength change Return loss decrease PDL increase FWHM increase Tunable wavelength range decrease	Same as VOA MEMS type		
			Reflectance of etalon mirror changing	Insertion loss increase Centre-wavelength change Return loss decrease PDL increase FWHM increase	Same as VOA MEMS type		
		Collimator	Same as VOA MEMS type	Insertion loss increase Centre-wavelength change Return loss decrease PDL increase FWHM increase Tunable wavelength range decrease	Same as VOA MEMS type		
		Pigtail	Same as VOA MEMS type				
	PZT etalon type	PZT	PZT degradation	Driving voltage increase	High humidity Thermal stress Excess driving	Damp heat Change of temperature Maximum absolute rating test On/off driving test	61300-2-19 61300-2-22 Understudy Understudy
		Etalon mirror	Reflectance of etalon mirror changing	Insertion loss increase Centre-wavelength change Return loss decrease PDL increase FWHM increase	Same as VOA MEMS type		
		Optical part and collimator	Dislocation of fixing points of optical parts	Insertion loss increase Centre-wavelength change FWHM increase Tunable wavelength range decrease	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Tunable filters (electrical control)	Thin film filter mechanical control type	Moving part	Stacking the moving part	Uncontrollable	Same as VOA mechanical type		
			Degradation of moving part	Driving power increase	Same as VOA mechanical type		
			Thin film filter degradation	Insertion loss increase Centre-wavelength change FWHM increase	High humidity (non-hermetic sealed)	Damp heat	61300-2-19
		Collimator	Same as VOA MEMS type	Insertion loss increase Centre-wavelength change Return loss decrease PDL increase FWHM increase Tunable wavelength range decrease	Same as VOA MEMS type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Dynamic chromatic dispersion compensators	VIPA type	Moving part	Degradation of stepping motor	Uncontrollable Dynamic range of CD decrease	Thermal stress Mechanical stress Excess driving High humidity (non-hermetic)	Shock (storage) Vibration (storage) Shock and vibration (operating) Change of temperature Maximum absolute rating test On/off driving test Damp heat	61300-2-9 61300-2-1 Understudy 61300-2-22 Understudy Understudy 61300-2-19
		VIPA mirror	Distortion of VIPA mirror	Centre-wavelength change Insertion loss increase GDR increase	Thermal stress High humidity (non-hermetic) Mechanical stress	Change of temperature Damp heat High temperature Shock (storage) Vibration (storage)	61300-2-22 61300-2-19 61300-2-18 61300-2-9 61300-2-1
			Temperature uncontrollable	Centre-wavelength change Insertion loss increase	Thermal stress High humidity (non-hermetic) Mechanical stress	Change of temperature Damp heat High temperature Shock (storage) Vibration (storage)	61300-2-22 61300-2-19 61300-2-18 61300-2-9 61300-2-1
		Optical parts and collimator	Dislocation of fixing points of optical parts (3D mirror distortion)	Insertion loss increase Centre-wavelength change Dynamic range of DC decrease GDR increase	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature Damp heat High temperature Shock (storage) Vibration (storage)	61300-2-22 61300-2-19 61300-2-18 61300-2-9 61300-2-1
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Dynamic chromatic dispersion compensators	FBG thermal control type	Thermal control part	TEC/heater degradation	Insertion loss increase Wavelength range change Dynamic range of CD decrease	Thermal stress High humidity (non-hermetic) Mechanical stress Excess driving	Change of temperature Damp heat High temperature Shock (storage) Vibration (storage) Maximum absolute rating test On/off driving test	61300-2-22 61300-2-19 61300-2-18 61300-2-9 61300-2-1 Understudy Understudy
		Fixing point between FBG and temperature control	Fibre bending	Insertion loss increase Wavelength range change CD changing GDR increase	Thermal stress High humidity (non-hermetic) Mechanical stress	Change of temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-19 61300-2-9 61300-2-1
		FBG	Refractive index changing	CD changing	High temperature	High temperature	61300-2-18
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Dynamic gain tilt equalizers	Magnet optic type	Magnet optic part	Dislocation of magnet, Faraday rotator and birefringent crystal	Insertion loss increase Tilt change Return loss decrease PDL increase WDL increase	Same as VOA MO type		
		Collimator	Same as VOA MEMS type	Insertion loss increase Tilt change Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
		Pigtail	Same as VOA MEMS type				
	Planar waveguide type	Waveguide	Refractive index changing	Insertion loss increase Tilt change Return loss decrease PDL increase WDL increase	Same as VOA PLC TO type		
			Electrode degradation	Dynamic range of tilt change	Same as VOA PLC TO type		
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Same as VOA PLC TO type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Dynamic channel equalizers	MEMS & diffractive grating type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as VOA MEMS type		
			Reflectance of mirror changing	Insertion loss increase Attenuation change Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
		Diffractive grating, lens, prism and Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
		Pigtail	Same as VOA MEMS type				
	Liquid crystal & diffractive grating type	LCD	Degradation of LCD	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as VOA LCD type		
			Electrical polarization of LCD	Uncontrollable	Same as VOA LCD type		
			Freezing of LCD	Uncontrollable	Same as VOA LCD type		
		Diffractive grating, lens, prism and Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as DCE MEMS type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Wavelength blockers	MEMS & diffractive grating type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as VOA MEMS type		
			Reflectance of mirror changing	Insertion loss increase Attenuation change Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
		Diffractive grating, lens, prism and Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as DCE MEMS type		
		Pigtail	Same as VOA MEMS type				
	Liquid crystal & diffractive grating type	LCD	Degradation of LCD	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as VOA LCD type		
			Electrical polarization of LCD	Uncontrollable	Same as VOA LCD type		
			Freezing of LCD	Uncontrollable	Same as VOA LCD type		
		Diffractive grating, lens, prism and Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as DCE MEMS type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Wavelength selectable switches	MEMS & diffractive grating type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as VOA MEMS type		
			Reflectance of mirror changing	Insertion loss increase Attenuation change Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
		Diffractive grating, lens, prism and Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as DCE MEMS type		
		Pigtail	Same as VOA MEMS type				
	Liquid crystal & diffractive grating type	LCD	Degradation of LCD	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as VOA LCD type		
			Electrical polarization of LCD	Uncontrollable	Same as VOA LCD type		
			Freezing of LCD	Uncontrollable	Same as VOA LCD type		
		Diffractive grating, lens, prism and Collimator	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Same as DCE MEMS type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Wavelength selectable switches	Planar waveguide type (thermal optic effect)	Waveguide	Refractive index changing	Insertion loss increase Crosstalk increase Return loss decrease PDL increase	Same as VOA PLC TO type		
			Electrode degradation	Crosstalk increase	Same as VOA PLC TO type		
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Same as VOA PLC TO type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Wavelength selectable switches	Planar waveguide & MEMS type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Insertion loss increase Isolation decrease Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
			Reflectance of mirror changing	Insertion loss increase Isolation decrease Return loss decrease PDL increase WDL increase	Same as VOA MEMS type		
		Waveguide	Refractive index changing	Insertion loss increase Attenuation change Isolation decrease Return loss decrease PDL increase WDL increase	Same as VOA PLC TO type		
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Same as VOA PLC TO type		
		Fixing point of MEMS, lens and mirror	Dislocation of fixing points of optical parts	Insertion loss increase Attenuation change Isolation decrease Return loss decrease Dynamic range of attenuation decrease PDL increase WDL increase	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Channel monitors (Performance monitors)	MEMS tunable filters & PD type	MEMS	Stacking the moving part	Uncontrollable	Same as VOA MEMS type		
			Distortion of hinge/mirror	Wavelength deviation Wavelength dynamic range change	Same as VOA MEMS type		
			Reflectance of mirror changing	PD current decrease (Error increase)	Same as VOA MEMS type		
		PD	PD degradation	PD dark current increase	Electrical surge High temperature Excess driving	ESD High temperature Maximum absolute rating test	? 61300-2-28 Understudy
		Collimator	Dislocation of fixing points of optical parts	PD current decrease (Error increase) Return loss decrease	Same as VOA MEMS type		
		Pigtail	Same as VOA MEMS type				
	Thermal tunable filter & PD type	Thermal tunable filter	Filter refractive index change	Wavelength deviation Wavelength dynamic range change	High temperature Excess driving	High temperature Maximum absolute rating test Driving test	61300-2-18 Understudy Understudy
			Electrode degradation	Wavelength dynamic range change	Electrical surge High temperature Excess driving	ESD High temperature Maximum absolute rating test	Understudy 61300-2-28 Understudy
			Transmittance of tunable filter decreasing (loss increasing)	PD current decrease (Error increase)	High temperature Excess driving	High temperature Maximum absolute rating test Driving test	61300-2-18 Understudy Understudy
		PD	PD degradation	PD dark current increase	Same as channel monitor MEMS type		
		Collimator	Dislocation of fixing points of optical parts	PD current decrease (Error increase) Return loss decrease	Same as VOA MEMS type		
		Pigtail	Same as VOA MEMS type				

Table 2 – Failure mode and known failure mechanisms for optical units of dynamic devices (continued)

Dynamic devices		Constitution parts	Known failure mechanisms	Failure modes	Degradation acceleration factors	Relevant tests	IEC references
Channel monitors (Performance monitors)	Planar waveguide & PD array type	Waveguide	Refractive index changing	Insertion loss increase Tilt change Return loss decrease PDL increase WDL increase	Same as VOA PLC TO type		
		Fixing point between waveguide and fibres	Dislocation by the degradation of adhesive	Insertion loss increase	Same as VOA PLC TO type		
		PD array	PD degradation	PD dark current increase (Error increase)	Electrical surge High temperature Excess driving	ESD High temperature Maximum absolute rating test	Understudy 61300-2-28 Understudy
		PD fixing point	Dislocation of fixing points of PD array	PD current decrease (Error increase)	Thermal stress High humidity (non-hermetic sealed and using adhesive) Mechanical stress	Change of temperature High temperature Damp heat Shock (storage) Vibration (storage)	61300-2-22 61300-2-18 61300-2-19 61300-2-9 61300-2-1
		Pigtail	Same as VOA MEMS type				