

WDM Network Management: Experiences gained in a European Field Trial

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Abstract

The European research project MOON (Management of Optical Networks) has developed a concept for the management of optical WDM (Wavelength Division Multiplex) networks based on the TMN architecture. This concept comprises the Operation, Administration, and Maintenance (OAM) mechanisms as well as an information model specified in GDMO (Guidelines for the Definition of Managed Objects). A prototype network called MOONET has been installed which extends over about 500 km and connects sites in Germany and Austria. In this network, the relevant components of the management concept are implemented in hardware and TMN software.

At present, field trial experiments are being carried out in order to evaluate the management concepts under realistic conditions of network operation.

This contribution describes the management concepts in terms of the functional architecture, the OAM concepts, and the information model. The infrastructure of the field trial is explained and an overview over the experiments is given. On the WDM layer, experiments on configuration and fault management are performed, where the focus is on fault management. Furthermore, aspects of the inter-working between the WDM layer and ATM as a client of the network are studied.

Keywords

Network Management, TMN, OAM, Optical Networks, Field Trial, Information Model, TMN Operation System, Functional Architecture.

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1. Introduction

At present, Wavelength Division Multiplexing (WDM) transmission technology is being deployed widely in backbone networks in the US as well as in Europe. The next step of evolution will require to network these point-to-point systems. In order to enable this migration, research on WDM networks is progressing rapidly addressing the management of these networks as a crucial topic [1-5]. In standardization, basic building blocks of the management concept such as the functional architecture [6] and the requirements on optical networks [7] are already available as draft versions.

On the level of research, first versions of information models for the management of optical networks as well as OAM (operation administration, and maintenance) concepts have been defined in the research projects MOON, MEPHISTO, and MONET [3,4,5].

Experience has shown that a management concept cannot to be developed as a pure paperwork. In order to be directly applicable, practical experience from implementation of hardware and TMN software is necessary and extensive testing under realistic conditions has to be done. For this purpose, field trial experiments are an excellent means.

The transition from theoretical elaboration of TMN concepts to the evaluation in field trial demonstrators takes place at this point in time. The field trial of the European ACTS project MOON has been started mid of October and will be finished in February '99. The experiments aim at evaluating the management concepts and the information model developed in the course of the project.

For this purpose, hardware of an optical network has been implemented as well as the major components of the management architecture such as components for the supervision of the signal, implementation of the OAM flows, and agent and manager software. The MOONET field trial extends over about 500 km and connects sites in Munich and Passau in Germany, and Schärding and Vienna in Austria by a meshed all-optical network (see Figure 1). The network is designed to carry 8 channels on an optical fiber, where 4 channels are actually equipped for the field trial.

Optical client signals of different wavelengths can be fed in or received at the optical terminal multiplexers (OTMX) in Munich and Vienna or at the tributary ports of the optical crossconnects (OXC's) in Passau. Amongst others, SDH transmission systems with bit rate up to 10Gb/s are used as client signals for the experiments of the field trial. At the input port of the OXC's, the WDM signal is demultiplexed and the single wavelengths can be flexibly crossconnected to the different output ports where a new multiplex signal is generated. This allows to use the network as a flexible transport platform which, due to the analogue nature of transmission, can transport multiple client signals. In addition to the payload signals, OAM information can be exchanged between the network elements on dedicated optical channels (overhead channels) for the purpose of signal supervision.

In order to enable vendor independent management, the field trial network is designed according to the TMN Architecture. An Agent and a Mediation Device (MD) present the Management Information of the OXC's and the manageable optical line amplifier (OLA) to the TMN Operation System (TMN-OS) via a Q₃ Interface.

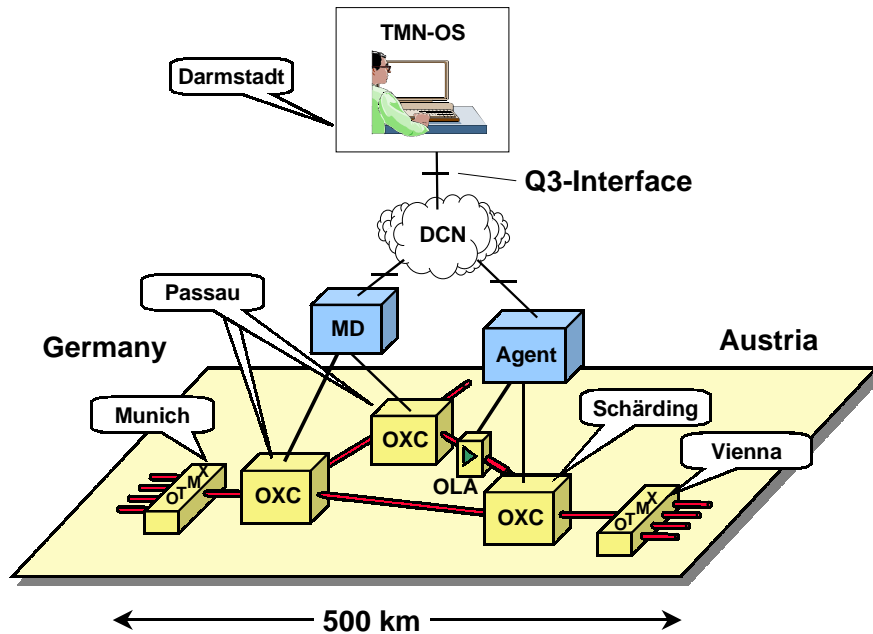


Figure 1: The MOON field trial network. Abbreviations see text.

The setup of the field trial enables to study the interworking of all components relevant for management under realistic conditions of network operation. Furthermore, valuable information about aspects of implementation can be gained. Hence, the field trial enables to review the information model and the OAM concept in the light of the experiments of the field trial itself as well as from experience gained from implementation work.

This contribution describes the management concepts in terms of the functional architecture, the OAM concepts, and the information model. The hardware and software infrastructure of the field trial is explained and an overview of the experiments of the field trial is given. These experiments comprise Configuration and Fault Management. Furthermore, aspects of the interworking between the WDM layer and ATM as a client of the network is studied experimentally.

2. Modeling of the network element view for optical networks

The aim of the model is to describe the network resources from a management point of view. In principle, the functionality and the state of the network elements is described by a vast number of parameters and hence it is vital to describe all this information in a systematic way. As only properties relevant for management are to be considered, this implies a strong abstraction of the resources. Such an abstract description of the resources can be achieved using the method of functional modeling described in ITU-T Recommendation G.805 [8]. This method supports the basic requirement that the description must be independent of details which are specific for the vendor or a particular implementation. From the functional architecture, the object classes describing the transport of information can be derived. Furthermore, the functional architecture allows to describe OAM flows in a comprehensive way. The application of the method to optical networks is described in [6].

The basic idea of the approach is to identify the basic functionalities of the network and to assign them to different layers. Between these layers, a client-server relationship exists. Figure 2 displays the basic functions implemented in optical networks.

These basic functionalities are: optical (1R)- regeneration (eventually with dispersion compensation), multiplexing and demultiplexing, and establishment of crossconnections and of an end-to-end view in the network. An optical line amplifier (OLA), for instance, implements only regeneration, whereas an optical crossconnect (OXC) or an optical terminal multiplexer (OTMX) may also perform any of the other functionalities described above.

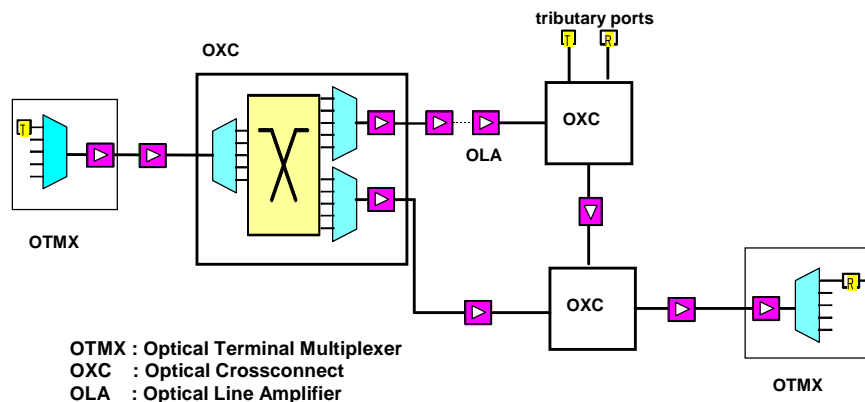


Figure 2: Basic functions in a WDM network

In the functional architecture (see Figure 3) the functionality of the network is mapped to different layers in the following manner: optical regeneration and

dispersion accommodation is assigned to the optical transmission section layer (ots), multiplexing and demultiplexing is described by the optical multiplex section layer (oms). The establishment of crossconnections and of an end-to-end view in the network is assigned to the optical channel (och) layer. Each of the layers work on a specific format of data which is called the characteristic information. The characteristic information of the ots layer is a multiwavelength signal with varying amplitude whereas the characteristic signal of the oms layer is described by a multiwavelength signal with an amplitude which is within a certain range. The characteristic signal of the och layer, at last, is logical in nature and corresponds to a single wavelength signal. The adaptation between the different formats of the characteristic signal of each layer is performed by the adaptation functions denoted by trapezoids in Figure 3. The termination function which is represented by triangles describes mechanisms which guarantee the integrity of the functions of the layer.

The assignment of the network element functionality to different layers and again different functions within the layers gives a powerful means to arrange the related management information in a systematic way. The gray areas in Figure 3 indicate how the parameters and states which describe or control these functions can be mapped to objects of the information model. These object classes are derived from termination point objects specified in ITU-T Recommendation M.3100 [9] and contain the respective data in the form of attributes, related actions, notifications, and parameters.

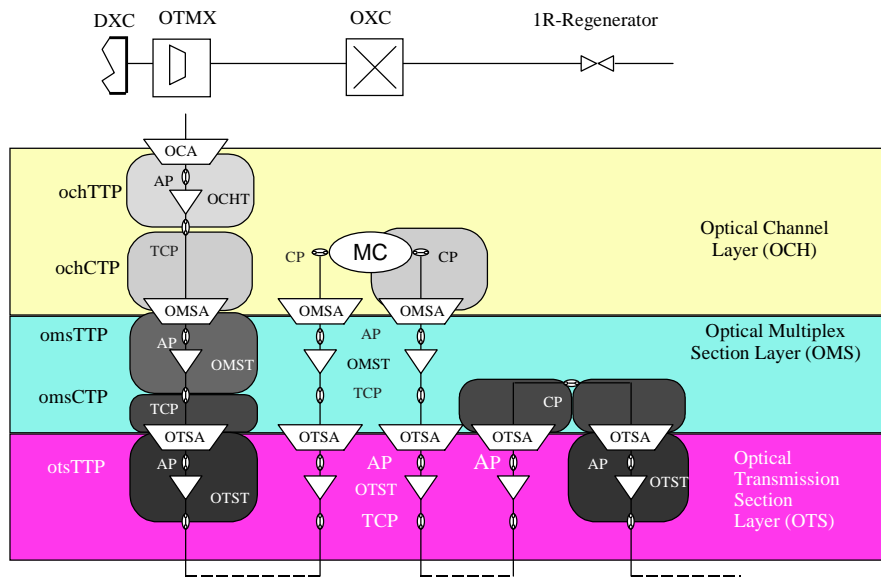


Figure 3: Functional architecture and transport objects

3. Fault Management and OAM Signaling

The functional architecture does not only form the basis for the development of the information model, it can also be used to describe the OAM messages exchanged between the network elements. The OAM messages are used in fault management to inform the network elements involved in the connection, to trigger consequent actions such as protection switching or laser safety and to support fault localization. For this purpose it is necessary that functional entities performing the same functionality can exchange messages which carry information about the fault conditions or possible reasons. In addition, in order to inform all network elements involved, an exchange of information between different layers is required. This is illustrated in Figure 4 using the structure of the MOONET field trial as an example.

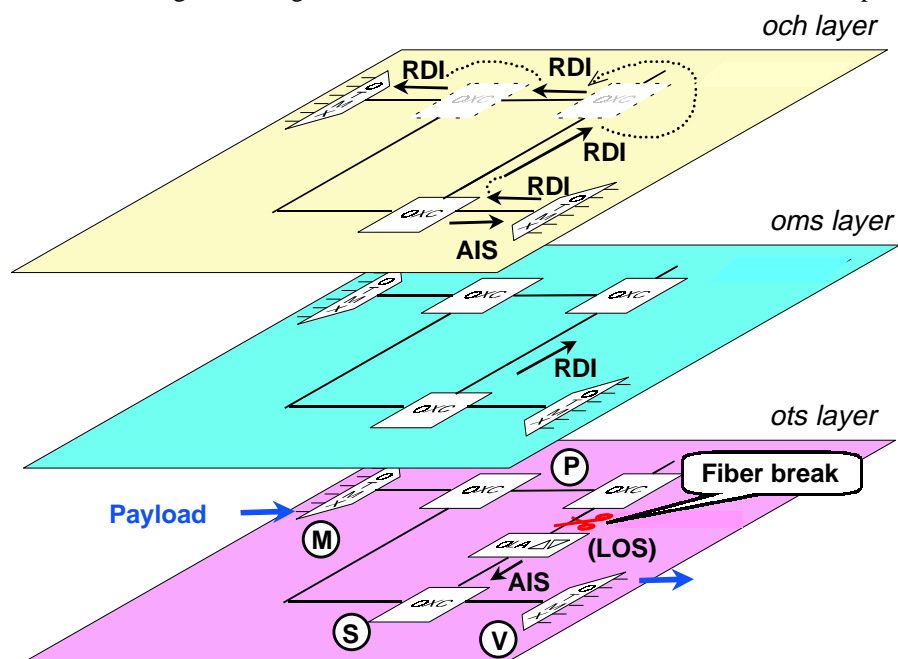


Figure 4: OAM flows for a unidirectional fiber break. Abbreviations see text.

The diagram shows the detected defect Loss of Signal (LOS) and OAM flows (associated with arrows) for the different layers of the functional architecture. The letters in circles denote the site of the equipment. M stands for Munich, P for Passau, where two crossconnects are located, S for Schärding, and V for Vienna. The failure scenario studies the case that one unidirectional connection is set up from Munich to Vienna and a unidirectional fiber break occurs between the optical crossconnect Passau2 (P2) and the optical line amplifier (OLA).

The OAM signaling takes place in the following steps: As a first reaction, the optical line amplifier located in Schärding (S) detects loss of payload (LOP) and

loss of overhead (LOH). From these two events, a defect called LOS (Loss of Signal) is derived. In the next step, the OLA transmits an alarm indication signal on the ots layer (otsAIS) to OXC Schärding and in addition an overhead failure indication signal (OHFIS, not shown here) in the same direction. Triggered by the otsAIS, the OXC Schärding inserts a remote defect indication on the oms layer (omsRDI) in direction to the optical crossconnect Passau2 (P2). This flow is terminated at Passau2 and leads to a notification to the TMN-OS. Stimulated by the detection of the otsAIS, the OXC Schärding emits an ocAIS to the OTMX in Vienna. After detection of the ocAIS, OTMX Vienna in turn inserts an RDI on optical channel level (ocRDI) in backward direction to inform the OTMX in Munich of the fault.

If this state is reached, all network elements involved are informed. On the other hand, the transport object instances which are associated to the entity that has detected a defect or received an OAM signal emit communication alarms to the TMN indicating the OAM signal received and eventually further related information. From these notifications, the TMN operation system can deduce a probable primary error by means of alarm correlation.

4. Relationship between Network Element Level and Network Level view

From an operator's point of view, the primary task of the management system is to establish, to supervise, and to release optical channel trails. Disregarding specialized configuration tasks, functionality on network element level (NEL) is mainly necessary to support the management on network level (NL) and to trace faults down to exchangeable parts. This illustrates that the definition of the network level view is very important for management as well as an appropriate specification of the relationship between both views. Figure 5 illustrates this relationship for termination point and crossconnection classes of the NEL view and the network level trail and connection object classes (dotted boxes).

Between the instances of these classes a large number of pointer relationship exists. These pointers reflect, for instance, the dependencies between the connections and trails on the different layers of the functional architecture making up the optical channel trail. Further relationships exist on network element level between the termination points and the equipment which supports the functionality of the termination point. The management system has to keep track of all these pointer relationships in order to maintain a complete view of the network level resources and their states. If, for instance, a set of crossconnections is created on network element level, the TMN-OS tracks all the pointer associations between the connection termination points described by the crossconnection until it ends up with the trail termination point on optical channel level (ocTTP) on both sides. Based on the set of pointer relationships found, the related ocTrail can be generated on the network level.

In the case of faults, termination points associated with faulty equipment may change the operational state which affects in turn the operational state of the whole ocTrail. It is the task of the TMN-OS to evaluate all notifications received on NEL and to map these to state changes of affected network level resources.

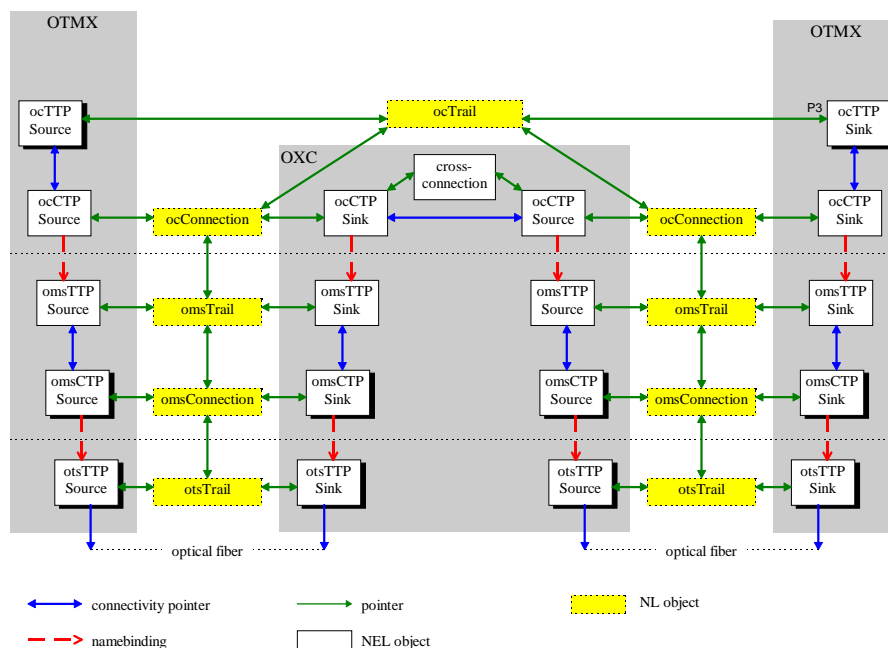


Figure 5: Relationship between NL-view and NE view

5. Implementation of the TMN-OS

For implementation of the MOON OS, a rapid prototyping approach [10,11] has been developed which introduces SDL (Specification and Description Language) into the development of TMN applications. The use of SDL helps to close the gap between specification and implementation and enables to build up the implementation to a large extent on the work done during the specification phase.

In order to achieve maximum reusability of the software developed the TMN-OS architecture (see Figure 6) has been designed in a modular way where generic components are used wherever possible. Generic components can perform their functionality independently of the specific management context the application is designed for. Examples for generic components are a Java GUI, which enables the user to access the NEL- and NL- MIB, and the Q₃ communication gateway, that performs the processing of CMIP Protocol Data Units for communication between the network elements and the internal modules of the application.

Application of generic modules implies to leave as much intelligence as possible in the core application modules themselves. These are the Network Element Level -

OS, the Network Level-OS and the GUI server. These modules implement the Network and Network Element Level Management Functions and the Communication with the Graphical User Interface respectively. Their functionality has been specified in SDL. Using the approach described in [10,11] C code can be deduced almost automatically from that specification.

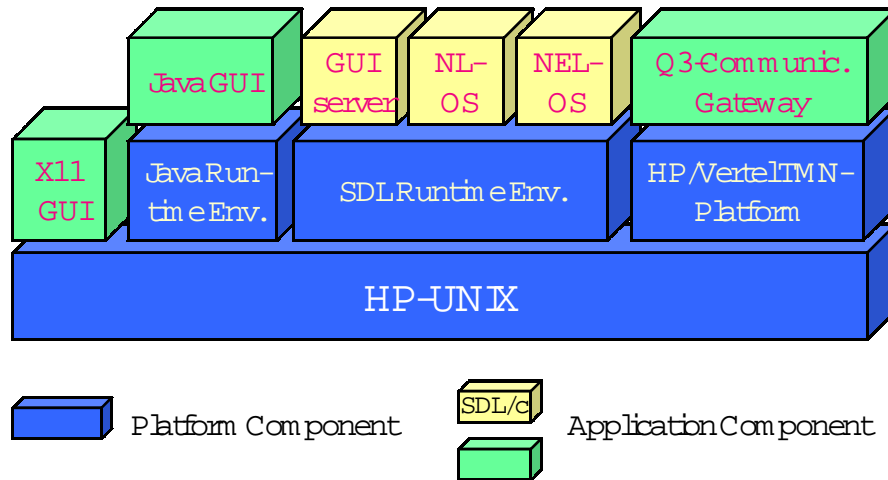


Figure 6: Software Architecture of the TMN-OS

The portion of the code that had to be produced manually for those three modules of the MOON application was less than 1%.

Deriving the implementation directly from the specification has several merits: First, a strong reduction of development time can be achieved. Secondly, rapid adaptation to changes in specification possible (extension of functionality) is possible. Thirdly, as the part of manually produced code is very small and the SDL specification uses an intuitive, graphical representation, the probability of errors in the code can be reduced dramatically.

6. Experiments of the field trial

In the sections before, the basic TMN concepts and aspects of their implementation have been described. The experiments of the field trial aim at evaluation of the concepts as well as of the implementation. They have started mid of October 1998 and will finish in February 1999. In this context, two sorts of experiments are to be distinguished, namely experiments related to the functionality of the WDM layers and experiments related to dependencies between the WDM layer and the client layer regarding performance. These two topics will be described in the next two subsections.

6.1 Experiments related to the WDM layer

In the field trial, experiments on fault and configuration management are being performed. In the following, the focus of description is mainly on fault management, as on this area the complex inter-working of all the components, namely the hardware, the OAM flows, the agents and the TMN-OS can be studied in detail. The main aim of these experiments is to identify eventual functional deficiencies in the TMN-concept in order to be able to rectify them in the specification of the OAM mechanisms or in the final version of the MOON information model.

Figure 7 gives an overview of these experiments. The basic idea is to intentionally induce on the level of the hardware different errors by imposing additional attenuation or simulating fiber breaks, by variation of the optical output power of line amplifiers, by coupling in additional noise or causing frequency drifts of the laser sources. In addition, equipment malfunction such as the failure of electrical power can be simulated.

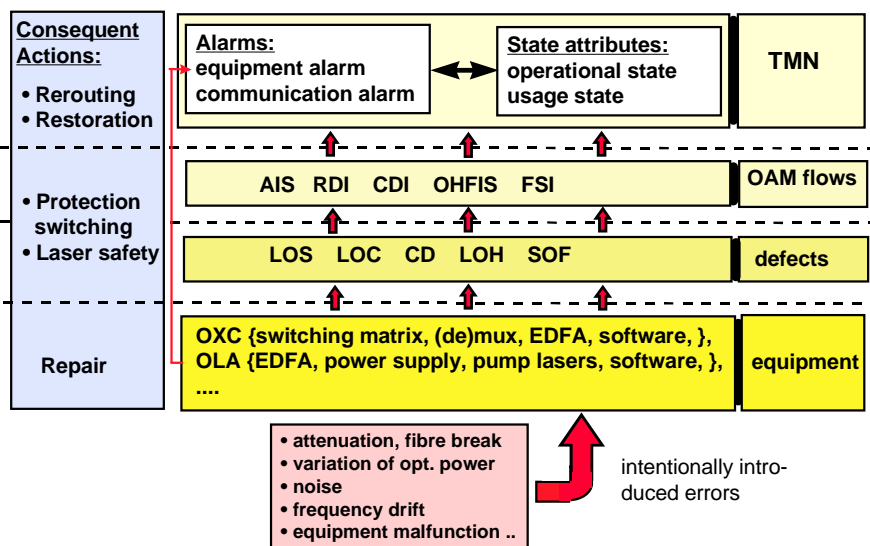


Figure 7: Overview of experiments related to fault management (abbreviations see text)

The hardware is able to recognize these failures and either directly notifies them to the TMN (for instance as equipment alarms in case of power failure) or maps them to internal signals of the network element called „detected defects“. These are: loss of payload (LOP), loss of overhead (LOH), loss of signal (LOS), loss of channel (LOC), channel degrade (CD), or shift of frequency (SOF). Triggered by the detected defects, this information is conveyed to other network elements in the form of the OAM flows alarm indication signal (AIS) to inform downstream

network elements, remote defect indication (RDI) to inform upstream network elements, channel degrade indication (CDI), frequency shift indication (FSI), or overhead failure indication signal (OHFIS).

Network elements which receive OAM flows can notify this to the TMN-OS. Furthermore, depending on the kind of OAM flow, network element resources such as termination points or network level resources such as connections or trails may change their operational or usage state. The conditions under which these notifications are emitted and the exact format and information contents are specified in the information model. The same is true for the state changes of the network element level resources. Based on the knowledge of the information model, the operator of the TMN-OS can deduce possible primary errors from the notifications received. This may be supported by alarm correlation algorithms provided by the TMN-OS.

Experience from two months operation of the field trial show that the mechanisms implemented for management allow a stable and flexible operation of the field trial network. The experiments on configuration management confirm a smooth interworking between the TMN-OS and the agent systems provided by different vendors enabling a flexible and reliable configuration of optical channel trails. where also incorrect requests or faults in the network are treated correctly.

For Fault Management, a first inspection of the experiments performed so far has shown that the OAM signals introduced give sufficient information for fault localisation. On the other hand some signals such as the FSI (frequency shift indication) and CDI (channel degrade indication) appear to be of minor importance for fault localization. Similar to the RDI signal, these signals indicate the respective defects in backward direction. As they do not induce a consequent action in the network element that receives these signals, it should be considered to cover them in general by an RDI signal. From the TMN point of view this would be no restriction, as the information about details of the problems is available in the currentProblemList of the Termination point.

Regarding fault management on TMN level it is important to have on one hand important events notified by the agent and to avoid on the other hand alarm floods caused by periodic reports of pending alarms or notifications related to quantities of minor relevance. The experiments have shown that the manager and the different agent implementations reflect a different understanding of the meaning of some alarms. This means that the conditions for the emission of communication alarms have not been specified unambiguously in the information model. The same is true for attribute value change and state change notifications. These notifications carry important information for the TMN-OS, whereas notifications on attributes such as the signalPowerLevel are redundant as critical events are notified by communication alarms. This input from the field trial experiments has been incorporated into the final version of the information model by a thorough revision of behaviour description.

A further issue to be studied is related to the analogue character of the network. This property calls for an accurate supervision of the optical parameters such as

power and optical noise. In contrast to digital systems, different levels of alarms have to be used which leads to a increased importance and more refined definition of threshold attributes. In operation of the trial reasonable values have been identified for these analogue values. Stable network operation is possible for the threshold values of 10 GHz for SOF (shift of frequency) and - 8 dBm for LOS (loss of signal) were sufficient, respectively. For the optical SNR, values smaller than 18dB should be chosen in order not to generate the detected defect CD (channel degradation) within a working MOONET. From the point of view of the client signal the measurements of ATM transmission experiments show that these values can even be reduced further significantly.

6.2 Experiments on inter-working between WDM and client layers

One of the major advantages attributed to WDM networks is their capability to transport, within certain limits, signals of different data rates, line codes, and formats within the same network. This property which is called „transparency“ gives the operator the means to build up very quickly specialized networks and to respond flexibly to client requests even for unusual data formats. This advantage, on the other hand, complicates operation of the network as supervision of data transmission is limited to parameters of the optical layer and no direct measure of the quality of the client signal is available. For this reason it is important to study the relationship between the performance of the client layer signal and optical parameters of the WDM network which are available to the management system. This aspect will be studied in the course of the field trial.

A sketch illustrating the basic ideas of the experiments is shown in Figure 8. The aim of the experiments is to show, using ATM as an example, how optical parameters such as attenuation, optical noise (possibly dispersion), and fiber breaks reflect in the performance of the client transport service.

For the experiments, an ATM (over SDH) signal is conveyed via an optical channel trail of the WDM network. The 155Mbit/s ATM signal is transported in a STM16 frame (2.5 GBit/s). During transmission, the performance of the ATM service is measured by a loopback configuration using an HP75000 ATM Tester. The ATM parameters studied are cell loss ratio (CLR), cell error ratio (CER), severely errored cell blocks (SECB), and unavailability. In order to study the dependency of the parameters of the optical layer, these optical parameters are varied in a reproducible manner, for example by imposing a link with an additional attenuation or by simulating fiber cuts. The aim of these experiments is to study how far the respective parameters of the optical layer can degrade until the client layer is impacted.

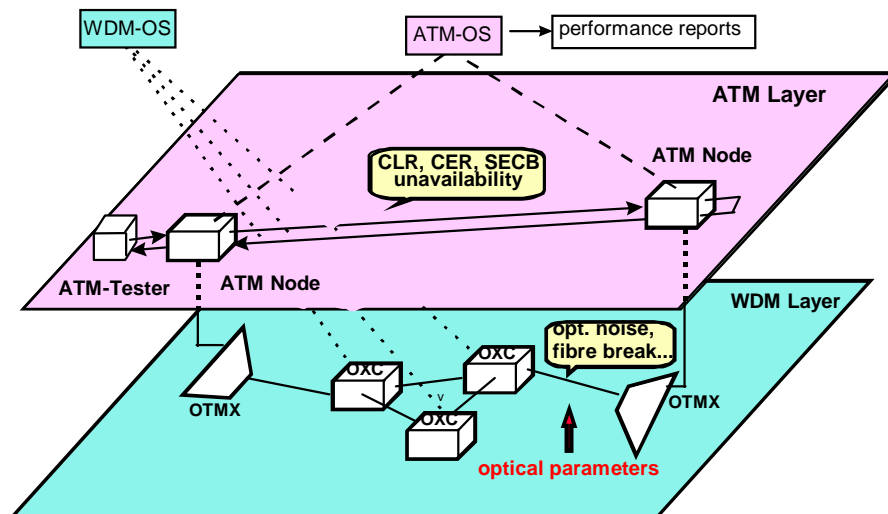


Figure 8: Schematic scenario for inter-working tests between ATM and WDM

The experiments are performed in a reproducible way using calibrated attenuators and it is expected that a mapping between performance parameters of the digital service and analogue parameters can be achieved. This enables to specify reasonable values for thresholds on the optical layer.

First results indicate that the system margin of the optical network is very high under the conditions described above. The performance of the ATM service was compliant with ITU-T recommendation I.356 [12] for insertion losses smaller than 27 dB.

Comparing the time of the variation of parameters of the optical layers, the reaction time on the WDM management system, and the reaction of the ATM -OS, the data can be correlated. This allows to measure the time span the failure takes to propagate between the different layers. Furthermore, the temporal behavior of protection switching facilities can be studied on the client layer as well as on the WDM layer. The evaluation and processing of the measured data takes benefit of the national ATM Management System of Deutsche Telekom AG and the ATM test equipment. The ATM management system can be used to accumulate and evaluate the necessary data which enables to correlate the events detected by the management of the ATM layer with those received by the management system of the WDM layer. In conjunction with protection switching on the optical layer, unavailability of the ATM produced by the time needed for protection has been measured. For a (1+1) protection on optical multiplex section layer, a mean interruption time of 20 ms has been measured for the ATM layer.

Conclusions

The results obtained from the MOON field trial so far show that the management concept developed enables effective and vendor independent management of optical networks. In particular, the OAM signals and the associated TMN notifications have proven to give sufficient information for error localization. On the other hand, the experiments have helped to identify some ambiguities that were still present in the specification of the management interface. These have been eliminated in the final version of the information model and practical experience from implementation has been fed in. Having a tested management concept available opens the chance to dispose of an efficient management interface as soon as the market provides mature products for optical networks.

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