Provisioning of integrated IP over WDM services through the management plane

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***Abstract*- This paper proposes an alternative approach for providing Internet services over the Optical Transport Network by extending the telecom-style network management approach to the IP layer with the cooperation of MPLS connection-oriented technology. The appropriate synergy and integration of the two layers is performed with management functions capable of performing integrated provisioning of Label Switched Paths (LSPs) over optical channels, as well as integrated multi-layer fault and performance management.**

I. INTRODUCTION

Most trends in IP-WDM integration propose the extension if the distributed Internet network control approach to the Optical Layer using signalling mechanisms either in an Overlay model or a Peer model. This paper proposes an alternative approach for providing Internet services over the Optical Transport Network by extending the telecom-style network management approach to the IP layer with the cooperation of MPLS technology, which can be treated as a connection-oriented one. The appropriate synergy and integration of the two layers is performed with management functions capable of performing integrated provisioning of Label Switched Paths (LSPs) over optical channels, as well as integrated multi-layer fault and performance management. This approach is a mid-term solution, followed by a transition period where the control and management plane will interact with each other, till the signalling mechanisms gradually become mature both technically and related to the corresponding business models, and dominate the IP over optical area. The proposed management solution has been adopted and is being investigated by WINMAN[1], an ongoing European research and development project, whose aim is to offer an integrated network management solution for the provisioning of end-to-end IP connectivity services derived from Service Level Agreements (SLAs).

II. Control vs Management Approaches for Multi-layer Integration

A. Generic next-generation Network Architecture

The context of the problem faced in this paper is characterised by a generic network architecture consisting mainly by WDM and MPLS-capable IP equipment. The basic principles for the integrated IP/WDM network architecture are the following:

- WDM is considered as core/backbone technology forming the Optical Transport Network
- IP is always interconnected at the edges of the optical core/backbone as access technology to offer Internet services
- Intermediate layer technologies such as ATM and SDH are pushed out of the backbone and, if needed, could be used as access technologies to the OTN for traditional telephony, Digital Subscriber Line (DSL), third generation mobile or other services

Such network architecture is mainly being adopted by global Internet Service Providers or currently by Research and Education networks [1] wishing to offer IP over lambda/ fibre services to their customers. These services are realised by corresponding IP gigabit routers, which aggregate multiple customers in a Point of Presence (PoP) located at the edges of the deployed optical infrastructure. The grooming of multiple customers at Gigabit speeds in a PoP is usually called GigaPoP.

On the other hand, the optical infrastructure, gradually evolving from ATM/SDH to WDM, consists of different equipment and topologies such as Terminal Multiplexers interconnected as successive point-to-point arrays or Optical Add-Drop Multiplexers usually interconnected in rings. The next step envisaged by the Optical Transport Network (OTN) is to use mesh networks of all-optical switches or cross-connects (OXCs) being capable of switching and converting lambdas forming an end-to-end optical trail between edge equipment to serve IP or other services.

In the rest of the paper, focus is given in the direct IP/MPLS over WDM integration without any other layer equipment, but in some cases such as Generalised MPLS, the above context is extended to multi-layer integration including other layer equipment such as SDH, forming the network equipment stack as IP/MPLS/SDH/WDM/fibre.

[1] The "WDM and IP Network Management (WINMAN)" project http://www.telecom.ntua.gr/winman, started on July 2000, and is co-funded by the European Community under the IST Programme. The partners of the WINMAN consortium are: Lucent Technologies Nederland, Ellemedia Technologies Ltd., Telefónica I+D, Portugal Telecom Inovaçao, Hellenic Telecommunications Organization (OTE) SA, OTE Consulting, National Technical University of Athens, University College of London, Universitat Politècnica de Catalunya, and TTI Telecom. The views presented in this paper reflect the authors' opinions.

B. *Control and Management Plane Approaches*

The concept of "Control Plane" and "Management Plane" has been introduced in the B-ISDN Reference Model [2]. The control-based scheme is a real-time approach using signalling distributed protocols among network elements for service provisioning and traffic engineering and it is the approach that is used in the Internet. On the other hand, the management based-scheme is a near-real-time approach for managing the network through appropriate external interfaces that the network devices offer towards the operator. This approach is fostered by the Telecom Operators' community. In parallel, IP and WDM technologies provide distinct services to its customers, and their interaction is kept under the plain encapsulation of IP client layer packets in lower order server technologies. What has been proposed by most researchers is to extend the signalling mechanisms of the Internet to the WDM layer and control in an integrated way the two layers with the Internet style. This paper proposes not only preserving the telecom style approach in the Optical Layer, but also extending it into the IP layer for the provisioning of integrated Internet services using management functions.

Many standardization bodies as well as international fora have addressed the issue of integrating the control plane of the MPLS-capable IP and the WDM network elements (NE). The ITU-T study groups 13 and 15 are working on the direction of ASON/ASTN framework [3] and [4]. In parallel ASON is being followed by IETF [5], by different vendors Forums such as Optical Internetworking Forum (OIF) [6] and by multiple European research projects such as IST and EURESCOM [7]. The specification of the User to Network (UNI) interface between the IP and WDM NEs ([8], [9]) allowing the automated provisioning of end-to-end LSPs spanning the optical network is among other one of the basic goals of the above activities. The mapping of the signalling messages to the existing RSVP-TE and CR-LDP protocols ([10], [11]) is a step towards an integrated control plane. Furthermore IETF, through specific working groups, such as the IP over Optical one, has been investigating the area, and initially proposed the MPlambdaS framework [15] for the integration of MPLS and WDM, which was generalised for multiple layers with Generalised MPLS [16].

On the other hand, the appearance of the MPLS protocol makes the IP network resemble a connection-oriented network. This paves the way to extend network and service management to the IP layer. The motivation is to be able to automate the management of the network devices and hence to allow scalable network management solutions. TMF [12] has adopted and started specifying transport-technology-independent common management interface from the Element Management Layer towards the Network Management Layer (NML) and from the NML towards the Service Management Layer, sometimes called the "Open CORBA" interface. Such initiatives are the *Multi Technology Network Management Interface called MTNM* mainly towards the first and *Connection and Service Management Information Model called CaSMIM* mainly towards the latter. In this view, the necessity of an Integrated or Inter-technology NMS (INMS) is pointed out by most manufacturers, serving as an umbrella on top of the single technology management systems, providing southbound CORBA IDL interfaces towards the technology NMSs and northbound interfaces to the Service Management Systems (SMS).

One of the basic reasons for using the control plane is to speed up circuit provision, which otherwise (management plane) can take up to days or even months in the case of OChs. However, this is not the case with the network operators that have developed their own management systems, either WDM or IP/MPLS that allow hundreds of OChs or LSPs to be up or taken down each day by means of autorouting and network configuration tools. WINMAN is based on the latter approach, i.e. using the management plane for fast and efficient establishment of MPLS LSP or Optical Channels not only separately for each layer, but in an integrated way for both layers, providing integrated configuration, performance and fault management functionality.

III. Technical Approach

A. *Rational*

The integration of the IP and the WDM technologies is an issue of intense research. However, the majority of these proposals are based on the concept that such integration should be done through the control plane. On the other hand, little attention has been given to the integration of the IP and the WDM technology using the management plane. A hybrid solution has been proposed [17] as the outcome of analysing the technical maturity and customers needs of the two approaches. The solution proposed a very limited use of the control plane, mainly supporting automatic error detection and protection, and an extensive network management plane, supporting automatic discovery, set-up of connections and a series of other FCAPS management functions.

The solution proposed in the paper is more or less in this direction focusing on the management plane. The use of the control plane will not be possible until standard interoperable routing and connection set-up signalling protocols appear and extensive tests provide performance assurance. Fast connection selection and setup along with automatic protection switching in the optical or IP layer provided by the elements is the most important feature of the control plane that management functions such as restoration cannot compete. In this view, there could be a period of time where management plane could dominate integrated IP over WDM service provisioning taking advantage of the lack of standards and performance proof by the control plane. The transition period should allow the stable features of control plane to interact with the management plane and finally signalling mechanisms could gradually dominate the IP over optical area, provided that the corresponding business models can be applied in the Internet environment. One of the main problems in terms of the business model, especially of the so-

called peer model, is the separation of the administrative domains of the IP and optical areas, as well as the current limited demand for changing lambdas very frequently. For this reason and as a first step, the adoption of the management plane approach coupled with the possible cooperation of some control plane features is being proposed by this paper.
The above ideas are captured by WINMAN research project, specifying and developing a Network Layer Management System providing southbound interfaces towards the IP and WDM Network Management Systems and northbound towards the Service Management Systems. The architecture is technology neutral and can cope with other transport technologies like ATM or SDH, but these will not be implemented, since our focus of attention lies on the direct integration of IP over WDM networks.

B. The Business Model

The proposed solution is intended for two broad categories of customers being network operators or ISPs and third parties, such as Value Added Service Providers. These entities will make use of the system to increase revenues by offering improved and more efficient services to their clients by building and reselling sophisticated management solutions (i.e. Virtual Private Networks). ISPs or third parties may want to manage by themselves the capacity that they hire from a transport network operator and/or provide value added services (e.g. Extranets) to their clients. Both categories of customers have shaped the requirements of our system.
In the field of the services, two basic types are considered. The first type includes connectivity services that support real-time data transport over IP, like voice (VoIP) and multimedia (MoIP) applications. The second type embraces connectivity services for the establishment of Virtual Private Networks (VPNs). The objective is, however, to generalise the proposed solution to other services.

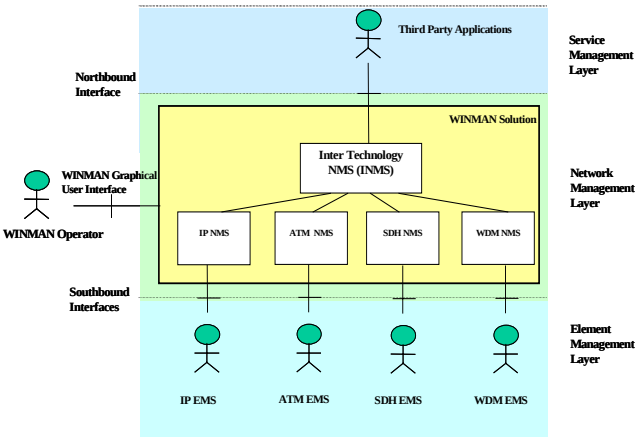

Fig. 1. WINMAN Business Model and System Architecture

In the above context, the proposed NMS focuses in the NML of the TMN pyramid. The reference points for interactions with the outer world is the northbound interface towards the Third Parties Service Management Functional Systems, such a VPN or VoIP, MoIP functionality systems and southbound to the Element Management Functional Systems. Within our scope are the IP and WDM technologies, since ATM and SDH functional systems will not be implemented. Finally, a presentation functional system is provided to the operator, as a means of visualising, controlling and monitoring the system and the underlying network. The above are summarised in Figure 1.

C. Proposed Management Architecture

The management architecture can be easily derived from the proposed business model. It is obviously based on an overlay model and identifies a management system for each technology i.e. IP/MPLS, ATM, SDH and WDM accompanied by one Inter-technology or Inter doamin management system, where domain refers to technology domain and not administrative one [13]. This paper focuses only on the INMS and on the MPLS-capable-IP and WDM management systems, since ATM and SDH have been dealt extensively in the past. The proposed system architecture is composed by one INMS and several NMSs devoted to the specific network technologies. The main focus will be the implementation of the INMS for Configuration, Fault and Performance Management with open interfaces to the Service Management and the Network Management Systems of the WDM and IP technologies complemented with a Graphical User Interface. The work done by TMF will be used as a starting point with the appropriate extensions to support the IP technology. Our intention is to define and implement a standard connection-oriented technology neutral interface supporting IP and WDM technologies. In addition, the WDM and IP NMS will be designed and implemented from scratch, following a technology-neutral internal architecture and providing in turn open interfaces towards the vendor-specific WDM and IP EMSs.
The following identified functional requirements have been considered per management area:
The Configuration Management application enables single point access to provisioning tasks and to end-to-end views of connections and their underlying infrastructure and facilities, independent of the technology. The main function is the Provisioning of end-to-end IP paths over light-paths using MPLS technology with QoS support. In this context the Inter Technology Management System should be capable of calculating, designing and creating MPLS Label Switch Paths (LSPs) over the corresponding light-paths in the optical layer. QoS support should be provided through the cooperation of MPLS with proper technologies supported by the equipment such as Differentiated Services.
The Fault Management application collects faults across different technology NMSs and determines the root cause and the layer responsible for the fault. Topology information and user-defined rules are applied to faults received from the NMSs' fault managers. The main function is the report and recovery of faults in the IP or Optical layer in an intelligent and integrated way. Reporting of primary faults and protection switching (the latter is a feature of the control

plane) should be supported after the corresponding filtering, analysis and correlation of the multiple alarms that are propagated in case of a single fault. The report should include all the attributes of the anticipated alarms together with the list of affected LSPs. An automatic fault restoration mechanism should apply to restore all the affected LSPs triggered by the inter- technology management system after the integrated analysis and correlation of the propagated alarms.

The Performance Management application collects data from the technology NMSs and processes these data in order to assess the performance of the network and the usage of the resources. Based on these assessment results, the operator is able to perform pro-active management of transport capacity across their multi-layer network and is able to perform pro-active management in order to prevent congestions (hot-spots) affecting the service in the network. The main function is to monitor, filter and report performance data. The INMS shall monitor the basic traffic and QoS network parameters of the LSPs along with other Service Level Agreements and report service degradations in case of performance gauges' or counters' threshold crossings.

IV. Domain Model

In order to support the above functionality the suitable management entities should be forecasted in terms of information model or internal system structures. In this view, the purpose of this chapter is to describe the so-called domain model entities relevant to the WINMAN management system external interfaces and internal structure and to present the different views in these interfaces. The domain model will be the basic source for the external WINMAN interfaces information models, as well as for the internal representation and adaptation among the different layers (IP, MPLS, WDM). In addition, the views in the corresponding external interfaces or internally in the system and to the WINMAN operator are described based on the domain model entities.

WINMAN will focus on a connection-oriented IP domain model, corresponding to MPLS technology. The use of IP connectionless technology in co-operation with MPLS is left for further study. In any case and based on the G.805 layered architecture [14] we identify 2 layers being MPLS and WDM, while in case we will use connectionless IP we will have 3 layers. In the latter case, MPLS will be serving as a server layer for IP. In the domain model, we have considered only MPLS entities and for clarity reasons, we replaced everything related to IP with MPLS, although the terms used are not successful in all cases. For this reason, the term IP or more important the term IP Connectivity Service (ICS) is used instead of MPLS Connectivity Sercive

According to the above hypothesis, we suppose that the MPLS domain starts with the Provider Edge IP equipment that is connected to the Customer Edge IP equipment and thus when traffic enters the proposed system responsibility (Provider Edge IP equipment), we assume that it is already marked as MPLS. However, the exact boundaries of the MPLS domain, will be further investigated in the lifetime of the project.

TABLE I
COMMON ENTITIES

Entity Name	Definition
Connectivity Service (CS)	A CS is the basic service delivered by the MPLS or WDM network and managed by WINMAN. The service is delivered either by the MPLS network meeting some QoS goals resembling a connection-oriented circuit or by the WDM network
Element Management System (EMS)	The Element Management System represents the abstraction of the sub-network(s) managed by theEMS (EMS management domain) and the element management system itself.
Termination Point (TP)	A termination point (TP) shall be a logical abstraction of an endpoint (actual or potential) of a topological (physical) link, or a subnetwork connection.A TP is contained within a managed element
Physical Termination Point (PTP)	A termination point that is an actual or potential endpoint of a topological (physical) link shall be abstracted as a physical termination point (PTP). Essentially, this is a representation of a physical port.
Connection Termination Point (CTP)	A Connection Termination Point is an actual or potential end point of a subnetwork connection.
Topological Link	A Topological Link is a physical link between two PTPs. A Topological Link has a name and references to the two PTPs. A Topological Link reported by an EMS to NMS will be between two managed elements (MEs) managed by the same EMS, and depending on the capabilities of the EMS and the MEs, a link may or may not be autodiscovered by the EMS.
Link connection	A link connection represents the transparent capacity of transfer information characterized by a given signal identification between two fixed points.
Subnetwork Connection (SNC)	A Subnetwork Connection relates Connection Termination Points. A Network Connection provides a transparent end-to-end connection through or within a subnetwork. The Subnetwork Connection may be created/deleted/modified by the INMS or Domain specific NMS and is implemented by the EMS.The Subnetwork Connection is contained in a Subnetwork.
Route	The route of a subnetwork connection shall be represented as an ordered series of CTPs names through which the subnetwork connection traverses, including the working and protect route. The protecting route is optional.
Managed Element (ME)	A Managed Element is an abstract class used to represent Network Elements visible across the interfaces.

A. Class diagrams

A transport technology independent generic domain model is being proposed, that will be applied for the two technologies under consideration, i.e. MPLS and WDM providing correspondingly the MPLS domain model and the WDM domain model. The generic domain model will be further enhanced and adapted for each of the two technologies. For example an entity such as CrossConnect Table (XC Table) will appear only in the MPLS domain model and not in the generic. The defined domain model will be the basis for the information models in the external interfaces. Such information models will be based on the MTNM (Southbound Interface in figure

1) and CaSMIM (Northbound and all other interfaces) adopted by the TMF, which will be further worked out and enhanced according to the needs.

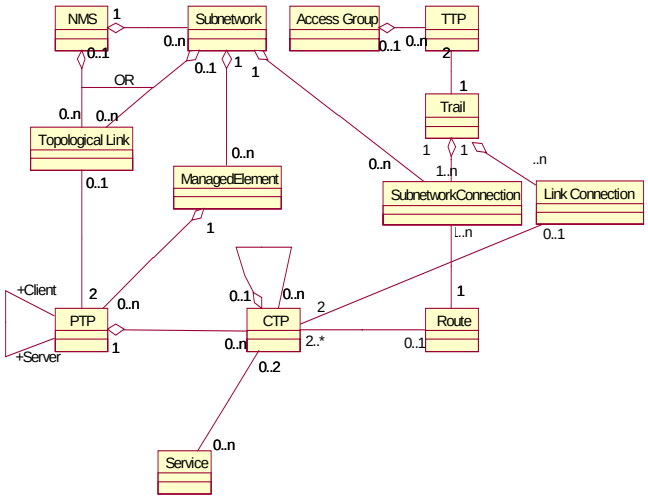

Fig. 2. Generic domain model

V. Internal and External Network Views

As already mentioned, the proposed WINMAN solution focuses in the Network Management Layer of the TMN pyramid. The interfaces for interactions with the outer world is the northbound interface towards the Third Parties Service Management Functional Systems, and southbound to the Element Management Functional Systems. A presentation functional system or Workstation function in TMN terms providing a workstation reference point is provided to the operator, as a means of controlling and monitoring the system and underlying network. Below, the views of the network providing different level of detail according to the positioning in the TMN pyramid and depending on the interaction with the corresponding entity will be given. Note that not only the network views on external interfaces are given, but also the internal WINMAN system views for the adaptation among multiple layers and for better visualisation for the WINMAN operator are provided.

The views are presented for the following internal or external interfaces:

- Integrated NMS to SMS
- IP NMS to INMS and WDM NMS to INMS
- Also different multiple and/or integrated views containing multiple layers will be presented

Note, that the terms and entities of the above-defined domain model will be used as much as possible, since not all entities can be used and visualised in the figures.

A. *INMS to SMS Network View*

The view in this external interface should be as abstract as possible. In this sense, the INMS need to show to SMS only the edge Physical Termination Points, which are the ones interconnecting the Provider edge equipment with the Customer Edge equipment (upper part of figure 3). Such PTPs are always MPLS PTPs and not WDM PTPs.

B. *IP NMS to INMS Network View*

The IP NMS will provide to the INMS the view that is depicted in the bottom part of figure 3 (outer ellipse). For simplicity reasons, the PTPs are not shown in the figure. Only the relevant CTPs are depicted. Between the corresponding CTPs exist the MPLS Subnetwork connections (MPLS-SNCs).

Note that the MPLS CTP interconnecting to the WDM network are marked with a single apostrophe (’), while the corresponding CTPs in the WDM will be later marked by a double apostrophe (”-quotation mark).

C. *WDM NMS to INMS Network View*

The WDM NMS will provide to the INMS the view that is depicted in the bottom part of figure 3 (inner ellipse). For simplicity reasons, the PTPs are not shown in the figure. Only the relevant CTPs are depicted. Between the corresponding optical CTPs exist the Optical Channel Subnetwork connections (Och-SNCs).

D. *Integrated or INMS internal View*

The integrated internal view is depicted in figure 3, where the MPLS sub-network ellipse includes not only the pure MPLS PTPs and MPLS-SNCs, but also the MPLS to WDM PTPs. The MPLS CSs are shown as concatenated MPLS and Optical SNCs, together with the corresponding optical link connections. Such a view can be considered as an internal view, necessary for the adaptation between the 2 layers and might be provided towards the WINMAN operator.

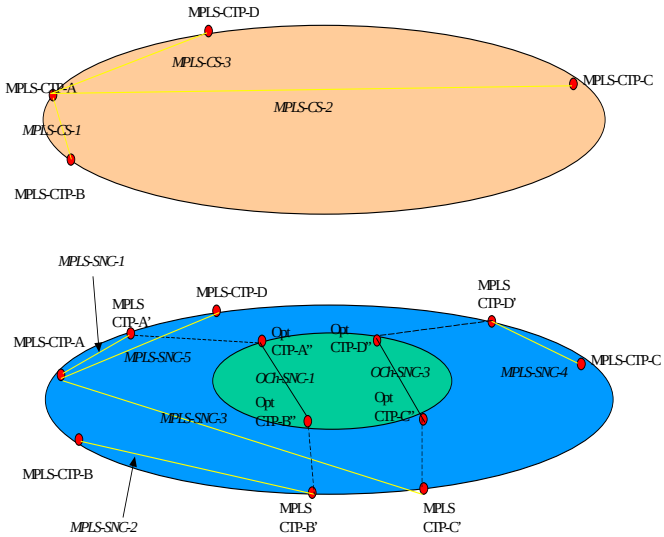

Fig. 3. Multiple SMS-INMS, WDM NMS-INMS, and IP NMS-INMS views

E. *Overall Network Model*

An example of the previous defined domain model entities providing the views analysed above is depicted in the following figure. In addition, some adaptation entities such as the trail and Trail Termination Points (TTPs) appear between the 2 layers, showing the corresponding adaptation functionality. In the following figures not all entities appear in an ellipsis to streamline them in a way that are easily understandable. For example, PTPs and CTPs, do not appear always in the same figure. In addition, Topological links and link connections appear separately.

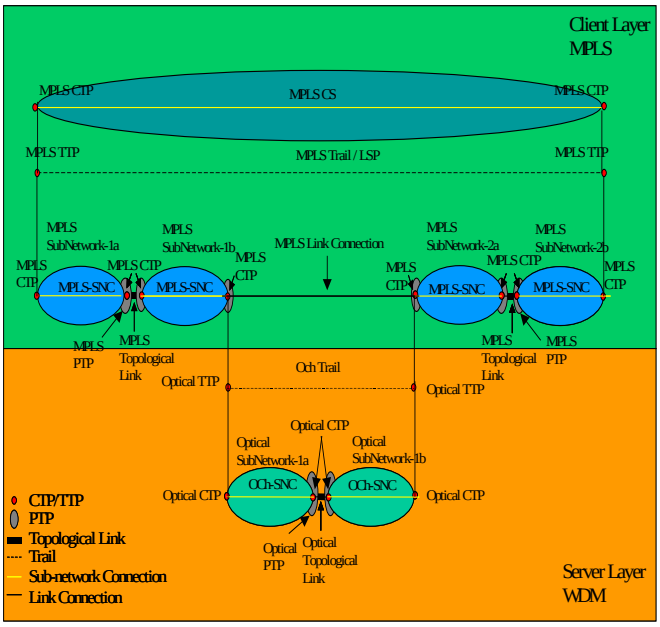

Fig. 4. Example of Domain Entities

VI. Conclusions

This paper gives an overview of the work carried out in the IST Project WINMAN whose main task is to develop and validate an open and flexible integrated management of IP over WDM networks. The project will contribute to the establishment and operation of worldwide IP over WDM networks. The trials envisaged in the WINMAN project would demonstrate inter-connectivity across a worldwide network management infrastructure in a multi-provider and multi-domain environment.

The proposed architecture and enterprise model of the initial WINMAN specifications makes possible the development, provision and validation of a novel Integrated Network Management architecture for future IP networks.

During its two-year and a half life span, the WINMAN project will develop and validate innovative solutions in the field of integrated management of IP over WDM networks.

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