A Generic End-to-end Distributed QoS Management Architecture and its application to IP-DiffServ over a WDM Access Feeder Network

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Abstract

The growing widespread use of advanced multimedia and interactive real-time applications is setting forth new challenges such as end-to-end Quality-of-Service (QoS) and broadband Internet access. The high bandwidth needs are pushing fibre closer and closer to the home, and as such WDM (Wavelength Division Multiplexing), seems ideally suited to be used in the broadband access feeder network which interconnects the Internet core networks and the last mile networks.

In the HARMONICS project\(^1\) (Hybrid Access Reconfigurable Multi-wavelength Optical Networks for IP-based Communication Services), a novel DWDM (Dense Wavelength Division Multiplexing) based optical access feeder network is investigated. This feeder network transports IP, guarantees QoS and can feed various last mile networks, stimulating the convergence of access networks. VDSL and Hiperlan/2 are studied within the project as last mile access networks.

To support end-to-end QoS, a distributed CORBA-based generic network management framework is being developed as part of the project. This paper will elaborate on the framework which is aligned with TINA, although adapted to be more consistent and applicable. End-to-end QoS is based on Differentiated Services (DiffServ) at layer 3, various QoS supporting technologies at layer 2 and QoS mappings between both layers.

Keywords
End-to-end QoS management, distributed management, DiffServ, CORBA, IP-over-WDM

1 Introduction and Motivation

The massive growth of next generation multimedia and real-time applications is asking more and more from the networks such as end-to-end Quality-of-Service (QoS) and

\(^1\)The HARMONICS project is co-funded by the European Community under the IST programme.
broadband Internet access. A variety of emerging advanced network technologies such as xDSL (Digital Subscriber Line) or wireless Hiperlan/2 tackle those issues for the last mile network. The high bandwidth needs are pushing fibre closer and closer to the home, and as such WDM (Wavelength Division Multiplexing), promising to provide the needed high bandwidth, seems ideally suited to be used in the broadband access feeder network which interconnects the Internet core networks and the last mile networks.

The HARMONICS (Hybrid Access Reconfigurable Multi-wavelength Optical Networks for IP-based Communication Services) project studies a DWDM based access feeder network carrying IPv4/IPv6 traffic directly over WDM with QoS guarantees. HARMONICS aims at stimulating the convergence of access networks by supporting a variety of last mile network technologies. Differentiated Services (DiffServ) is used as end-to-end QoS mechanism on Layer 3, supported on Layer 2 by a novel wavelength/timeslot MAC protocol in the Passive Optical Network (PON) and novel QoS mappings in the various last mile technologies.

To set up and manage end-to-end QoS connections, HARMONICS uses a distributed connection management software architecture. Users who require a prioritized connection, send a request (e.g. a Resource reSerVation Protocol (RSVP) message) to the management architecture. The network management checks whether the necessary resources are available or not, negotiates Service Level Agreements (SLAs) with neighboring networks, and makes the configuration changes to support this new connection.

Within the project, different scenarios are studied ranging from 64 Optical Node Units (ONUs), serving a total of 3200 VDSL subscribers, to 1024 ONUs for FTTH/B (Fibre-to-the-Home, -Building). The concept allows for migration, where the number of wavelength channels can be increased, while adapting the number of transceivers at the Optical Line Termination (OLT) to the maximum sustainable multiplexing gain.

This article however, focuses on both the end-to-end QoS provisioning at layers 2 and 3 and the generic end-to-end QoS connection management framework, paying special attention to the Optical Feeder Network (OFN). The considered line rates are 622 Mb/s upstream, and 1.2 Gb/s downstream for each channel and transceiver.

The remainder of this paper is structured as follows: Section 2 describes the HARMONICS network architecture in detail. Section 3 discusses how end-to-end QoS is achieved within HARMONICS, while Section 4 elaborates on the distributed QoS management software architecture. Section 5 presents a brief overview of the Lab and Field Trial and finally Section 6 concludes this paper.

## 2 HARMONICS Network Architecture

The HARMONICS broadband access feeder network consists of two main parts, as shown in Fig. 1: (i) the Optical Feeder Network (OFN) and (ii) the Last Mile Network (LMN) which supports multiple access networks based on various technologies. Interconnection of the various parts is accomplished by IP routers. HARMONICS Leaf Routers (LR) connect last mile networks to the OFN, while a HARMONICS Edge Router (ER) connects the OFN to the core network (= IP backbones).
The Optical Feeder Network (OFN) is basically an IP-over-WDM Network. From an IP point of view, the OFN is completely transparent – only the Edge Router at the core side and the Leaf Routers at the user side are visible. As such it provides Fibre-to-the-Curb (FTTC) and Cabinet (FTTCab), supporting various last-mile technologies. Residential or small office users can also use leaf Routers for FTTH/B configurations.

At the optical layer, the PON provides the connectivity between the Edge and Leaf routers. It is composed of a tree-and-branch PON connecting an OLT to different ONUs. There is a dedicated Leaf Router for every ONU, while the OLT is connected to the sole Edge Router. The HARMONICS PON deploys different multiplexing schemes to provide sufficient bandwidth across an area with a 20 km radius [1].

The PON design in Fig. 1 was selected after careful consideration of aspects such as power budget, component costs and compatibility with existing infrastructures. Space Division Multiplexing (SDM) is used at Local Splitting Centre 1 (LSC 1) by using a separate fibre for each AWG (Arrayed Waveguide Grating), Wavelength Division Multiplexing at LSC 2 by AWGs, and Time Division Multiplexing (TDM) by power splitters at LSC 3. The system is preferably deployed with a single type of ONU capable of transmitting at any channel wavelength, rather than several types each capable of transmitting at a single channel wavelength. For this reason, ONUs are equipped with reflective modulators that modulate their data on an optical DC signal which is broadcasted downstream by the OLT. Alternatively, the ONUs can use tuneable laser diodes, which are programmed downstream to a fixed wavelength during initialisation.

Dynamic reconfigurability of network capacity is performed by the optical cross-connect (OXC) at the Main Exchange (ME). The OXC maps the wavelength channels \((K,L)\) to a number of transceivers \(N_R\) of the OLT. Use of an OXC, composed of fast Semiconductor Optical Amplifier (SOA) gate arrays, is preferred over an electrical switch, since this reduces the number of required transceivers at the OLT. Moreover, switching in the optical domain allows for multiple line rates in the system and the possibility to by-pass...
a particular transceiver in the case of maintenance or other service disruptions.

Network Path Protection between the OLT and the LSC 2 is achieved by using a protected multi-fibre ring architecture to connect the AWGs to the OLT, where a dedicated fibre is used for each AWG. At the OLT location, $K$ protection switches are present, each either selecting the clockwise or counter clockwise direction in the ring. This configuration corresponds to a distributed LSC 1 power splitter.

**The Last Mile Network** provides a variety of access networks, each connected to at least one Leaf Router. Within HARMONICS, both a fixed (VDSL) access technology and a wireless (Hiperlan/2) access technology are studied for their seamless integration with the OFN. A detailed description of these last mile networks and their QoS possibilities however, falls outside the scope of this paper.

### 3 End-to-End Quality of Service

Performing basically the same role as IP — currently the layer 3 best-effort inter-networking protocol —, DiffServ has the added value of being able to offer end-to-end L3 QoS while offering scalability and compatibility with the existing IP.

Of course, if end-to-end QoS is to be guaranteed, shared layer 2 networks have to be QoS enabled and a QoS mapping between layer 2 and layer 3 has to be provided. Shared layer 2 networks involved in HARMONICS are the PON and the various last mile networks. Details on QoS implementation in the PON and QoS mapping between DiffServ and the PON can be found in Sections 3.2 and 3.3. QoS at layer 2 and the QoS mapping for the last mile networks are also investigated in HARMONICS but fall outside the scope of this article. The core networks (Internet backbones) are typically some layer 3 routers interconnected by constant bit rate (CBR) point-to-point links (which can be provided by a variety of layer 2 technologies with or without QoS). As such, there is no need to map L3 QoS parameters and connections to L2 QoS in the core networks$^2$.

#### 3.1 QoS at Layer 3: Differentiated Services (DiffServ)

To cope with a variety of layer 2 technologies while providing end-to-end QoS, DiffServ is used at Layer 3. DiffServ ([2, 3]) is the technique proposed by the Internet Engineering Task Force (IETF) to upgrade the existing best-effort IPv4 and the future IPv6 protocol to QoS enabled protocols. This is done by re-using an existing, currently unused (or rarely used) field in the IP header: 6 bits of the IPv4 Type-of-Service (ToS) octet or 6 bits of the IPv6 Traffic Class octet named the DiffServ Code Point (DSCP, [4]). All traffic marked with the same DSCP (called a Behavior Aggregate, BA) receives the same per-hop behavior (PHB) and thus the same QoS. Hence, DiffServ is very scalable regarding the number of flows, as only a limited number (max. 64) of QoS classes are supported.

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$^2$ QoS-matching between L2 and L3 is needed however: typically, a CBR point-to-point link is provided with an upper-bound on the delay (and eventually jitter). Those upper-bounds can be used to see which L3 QoS classes can be supported (matched) by these L2 links.
and the core routers only have to know about those DSCPs and their associated per-hop-behavior. All intelligence and computational intensive jobs (per flow or per BA classifying for DSCP (re-)marking, policing, shaping, . . . ) are moved to the edges of the networks where the number of flows can be handled. Those DiffServ edge and leaf routers\(^3\) have to be configured dynamically as they contain elements (markers, shapers, policers, . . . ) which are BA- or flow-dependent.

Currently, the following DiffServ per-hop-behaviors are standardized: 

- **Expedited Forwarding (EF, [5])** guarantees the highest QoS and can be compared to a virtual leased line with such properties as assured bandwidth, low delay, low loss, low jitter.
- **Assured Forwarding (AF, [6])** on the contrary is less stringent and only assures that the IP packets will be forwarded and not dropped if they are in-profile. There are no guarantees on delay and jitter. Of course, classical best-effort traffic remains also possible and doesn’t need any special treatment in the routers.

A main DiffServ advantage is that it is compatible with the existing IP protocol. Currently, most traffic has a ToS octet of zero, which means best-effort service in the DiffServ context.

### 3.2 A novel MAC to support QoS at the WDM access feeder

The HARMONICS OFN is dominated by the characteristics of a conventional (single channel) PON system. In contrast however, the presence of the optical cross-connect (OXC) prevents the employment of familiar medium access control (MAC) schemes, at least at the OLT. When a number of single channel ATM PONs would be connected to the core network by means of an external ATM switch, they can operate their own MAC. By incorporating a switch, the HARMONICS system is able to exchange the capacity between different channels, but it has to perform the MAC for all wavelength channels, as well as the switch itself.

**Downstream.** In the downstream direction, power splitting PONs implement the TDM allocation scheme in a relatively simple way by using a broadcast-and-select mechanism. The OLT attaches the destination ONU address to each data packet when it is transmitted, and the ONUs monitor the downstream data for their packets. The multi-channel WDM PON can perform the same, but here the MAC also needs to actuate the switch to connect the channel of the destination ONU to a particular transmitter.

**Upstream.** The most delicate aspect of access control in TDM PON systems occurs in the upstream direction in the power combiner. To avoid collisions of packets from different ONUs, very accurate synchronization is required between their transmitters. This alignment is complicated by the different distances at which the individual ONUs are located in the field. To solve this, the ONUs observe a transmission delay that is established during an initial measurement procedure (“ranging”).

**Optical packet switching.** An important issue is the choice of packet size. The use of variable packets (for higher layer protocols with variable packets) at the optical layer

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\(^3\) *Edge routers* are the routers at the boundaries of DiffServ domains working on a BA scale, while the *Leaf routers* are the first routers on the path from a host to the destination. The latter work on a per-flow base.
restrains the switching flexibility at the OXC considerably, since switching is only allowed at moments when gaps occur. By using fixed packet sizes, the MAC allows for flexible bandwidth allocation. A disadvantage is the need for segmentation and reassembly of network layer packets. The optical packets should be small to enable flexible allocation: the size of the smallest IP packet. The HARMONICS demonstrator will use 160 and 100 byte packets for downstream and upstream respectively, corresponding to 1.28 µsec. This keeps the relative overhead below 20%, low enough to allow for a usable bandwidth of about 1Gb/s downstream and 0.5Gb/s upstream. Unfortunately, different segments of a single packet still need to be transmitted to the same OLT receiver. Otherwise extra switching functionality is required to re-route the segments to the same reassembly unit.

**Access control and allocations.** For packets travelling downstream, there are no problems to access the medium (the fibers) as they all depart from a central point (the OLT). Upstream however, ONUs don’t know when other ONUs are sending, so access control is needed and the upstream direction is the main challenge of the MAC protocol. Access control can be seen as a continuous process involving three stages:

- **Assessment.** The central controller (residing at the OLT) must be informed when an ONU demands access. Within HARMONICS, there are 2 types of allocations possible in the optical feeder network. A *static* allocation is installed via the management framework and reserves a constant bitrate. A *dynamic* allocation however is allocated on the fly when there is data available at the ONUs and is done by the ONUs sending requests to the central controller (piggybacked to upstream packets or with special packets, called minislots). These dynamic allocations are typically used for Best-Effort traffic while the static ones are usually used for QoS connections.

- **Scheduling.** The controller determines which ONU is granted access. Detailed information about this falls outside the scope of this paper.

- **Notification.** The ONUs that are granted access are informed. The broadcast nature of the downstream traffic in PONs makes it attractive to apply in-band signalling. Even when no packet is addressed to it, an ONU can read every transmitted packet (which by the way illustrates the need for encryption in PONs). By attaching a second address to the downstream packets, the OLT is capable of submitting permits for every upstream packet. When an ONU receives a permit, it is granted to transmit a packet upstream, observing the time delay that was established during the ranging procedure. For the static allocations, the central controller at the OLT sends permits downstream as needed to cope with the made reservation. For dynamic allocations however, the packets are queued at the ONUs waiting for permits coming downstream answering the upstream dynamic requests (see *Assessment*).

### 3.3 Mapping of DiffServ QoS (L3) to the optical feeder QoS (L2)

The HARMONICS architecture is DiffServ-based at layer 3 to allow applications and users to select the network service (of which EF, AF and BE are standardized) that best suits their needs.

On the other hand, the MAC at layer 2 in the OFN considers only two kinds of traffic: firstly traffic with certain QoS constraints which has to be reserved by means of
the connection management framework (e.g. EF or AF which need reserved resources to avoid losses, high delays and jitter) and secondly traffic for which dynamic permits are requested by the ONUs and for which no QoS can be guaranteed (e.g. BE).

Note that for the downstream case, EF, AF and BE traffic receive the same QoS once they’re in the PON, but a differentiation is made at the HARMONICS edge router which has basic DiffServ functionality and as such prioritizes EF over AF over BE. For the upstream case however, EF and AF traffic is queued in the static allocated queues in the ONUs for which permits are generated automatically, while BE traffic is stored in the dynamic queues for which permit requests have to be sent by the ONUs. Hence, upstream, differentiation between EF, AF and BE is made both at the HARMONICS leaf router and in the PON.

4 End-to-End QoS Connection Management

To set up end-to-end connections with QoS guarantees, all networks along the path should be informed and queried (admission control) if a new connection can be provided. E.g. for DiffServ domains, this encompasses the configuration of leaf and edge routers (classifiers, DSCP markers, shapers, policers, ...) upon a positive response of the admission control for that domain. For the OFN, admission control and the subsequent configuration of the MAC protocol has to be fulfilled. Therefore, a management framework is proposed which takes care of these tasks. Note that this connection setup phase is only needed for connections with a higher QoS than best effort traffic, which will be the minority of the traffic. Hence, there will not raise problems of scalability regarding the number of connections.

The communication between the management components is based on CORBA (Common Object Request Broker Architecture). Key motivations for using CORBA are the following. CORBA provides an object-oriented framework, with a superior distribution paradigm in which every object could be potentially distributed. This feature comes in very handy when we want to build an architecture based on logically centralized, but physically distributed components. CORBA exhibits also standard mappings to multiple O–O programming languages based on a common language for the definition of the interfaces, namely IDL (Interface Definition Language). Finally, CORBA may become the ubiquitous technology for future heterogeneous distributed systems [9]. To provide a smooth communication between the CORBA components, on boot up of the management framework, high QoS paths with a dynamically adjusted bandwidth are reserved.

4.1 Concept of Layer Networks and Layer Network Co-ordinators

To ease the end-to-end co-ordination and management of different administrative domains and technologies, a generic layering and hierarchy model was introduced following the Divide et impera concept. The architecture and used terminology is based on proposals by the TINA Consortium (Telecommunications Information Networking Architecture, [10, 11, 12, 13]), although adapted to be more consistent and applicable.
The most important concept is Layer Network (Fig. 2). A Layer Network is a network consisting of a single technology (e.g. DiffServ, ATM, ...) and is restricted to a single administrative domain (e.g. an operator). One domain can contain several Layer Networks, each with another technology, as shown in the figure. Within the TINA Consortium, the term Layer Network is used to describe all network equipment of one technology in the whole world, but this isn’t a useful definition because of scalability issues.

Separate Layer Networks can have different relationships with each other as shown in Fig. 2. Both network layers 2 and 3 in the figure have the same Administrative Domains, which is only to not overload the figure. It would be perfectly possible e.g. that Administrative Domains 1 and 2 at L3 are only one Administrative Domain owned by one provider and as such there would be only one DiffServ Layer Network. The white arrows depict a possible user-to-user connection as studied in the HARMONICS project. At L3, only DiffServ is used while at L2 a variety of technologies exist. Because the core networks are generally using point-to-point links at L2, they are described generally as ‘Optical Core Networks’ in the figure, as their L2 (QoS) management falls outside the scope of this paper and a QoS mapping between L2 and L3 isn’t needed as already noted in Section 3.

A logical next step in the concept of Layer Networks is to introduce the Layer Network Co-ordinator (LNC) as a software entity which is responsible for the co-ordination of a single Layer Network and the negotiation with neighboring Layer Networks. Here we see why this terminology as used in the TINA specifications — one LNC for the whole world — isn’t very logical, in view of the structure of the Internet with the different domains. The LNCs are technology dependent and are only logically a single component. Practically they can be distributed by advanced distributed software techniques and load-balancing algorithms which make a scalable approach perfectly possible.

Applied to the HARMONICS project, Fig. 4 shows the different Layer Networks with their respective LNCs. This is the reference architecture which will be described in detail in the following sections. On top of the LNCs, optionally a service management architecture as described in [14] can be used to negotiate QoS matching at the application
4.2 DiffServ layer 3 multiple domain management

Within the HARMONICS project, DiffServ is the single technology used at layer 3 and as such only federation between different DiffServ Layer Networks is considered at that layer. At layer 2 a variety of technologies are under study, but the interworking between different layer networks can be handled by the common layer 3 technology, because a QoS mapping between DiffServ and the various layer 2 technologies is already being developed for the intra-Layer Network client-server relationship.

Fig. 3 shows a typical end-to-end situation and the federation relationships from a DiffServ layer 3 viewpoint (for simplicity Last Mile Networks are not drawn explicitly). Of course, instead of a backbone of only one provider, multiple backbones (and hence multiple Layer Networks) could be drawn. Note however that an average flow through the current Internet crosses about 1 or 2 backbones and 2 access networks, which can be checked on various traceroute websites. A LNC_{DS} (Layer Network Co-ordinator for DiffServ) is responsible for its DiffServ Layer Network and also for the negotiation with peering Layer Networks. The LNCs for the access feeder networks (domain 1 and 3) are logically and physically centralized in their respective domains as this imposes no scalability problems. A quick calculation with the Erlang formula \[7\], gives a worst-case scenario: the 64 channel OFN has a total amount of 64 Gbit/s downstream and 32 Gbit/s upstream. If this total bandwidth would be used for videoconferencing calls with a 2.5 Mbit/s bandwidth and we suppose a 0.0001 blocking probability, then there would be a load of approx. 30000 erlang, good for 6000 flows/minute with a mean duration of 5 minutes. This would impose a load on the management architecture of only 100 flow setup requests per second which is an upperbound as (i) VPNs or videoconferencing calls will take more than 2.5 Mbit/s, (ii) only part of the bandwidth will be used for QoS connections and (iii) the duration of these calls will be longer than 5 minutes. It should be possible for the multi-threaded management components, which parallelize the
different requests, to handle these. The LNC for the core network however is physically distributed and as such each sub-component only handles part of the flows. As described in Section 3, all configurable DiffServ leaf and edge routers are situated at the edges of the domains and as such it seems logical to bundle a couple of edge routers and manage them by a physically separated component, embodied by a CORBA object.

Regarding the IDL interfaces, each LNC has two types of interfaces: the i_boot_up interface which is meant for initializing the management architecture and the i_connection_setup_DiffServ interface which is used for setting up connections, see also Fig. 5. The object references to the i_boot_up interfaces of peering Layer Networks are well-known (i.e. they can be looked up in a CORBA Naming Service or they are manually provided by the ISP) and are used by an LNC to get the object references to the objects with a i_connection_setup_DiffServ interface.

An initialization scenario goes as follows: when the LNC of Layer Network 3 boots, it requests the LNC of domain 2 for a reference (or list of references, conn_setup_list) to an object(s) implementing the i_connection_setup interface while providing the network address (address) and technology (peer_technology) of domain 3. The latter two make it possible for the LNC of domain 2 to return the object reference to the most appropriate object (which is responsible for the right edge router and which speaks the same QoS parameters). Next, the LNC of domain 3 registers (register) itself (together with the network address and the type of technology of domain 3) with that particular object of the LNC of domain 2. From now on, both LNCs can reach each other to set up connections via the setup_connection interface method. As the LNCs have a federation relationship with each other, the QoS parameters are DiffServ related and the DSCP is the only QoS parameter in DiffServ (for simplicity, we assume that the DSCPs in the 2 domains are the same). This isn’t a big problem as the DSCPs for EF, AF and BE are standardized and non-standardized PHBs will be very likely supported by only one of the domains). The min_bandwidth and wanted_bandwidth parameters are the minimum needed and the wanted bandwidth to be reserved, while wanted_bandwidth will contain the effectively reserved bandwidth on return. The BandwidthDescriptions can be described in different manners (as described in the DiffServ MIB [8]): TokenBucket, AverageRate, Single Rate 3 Color (RFC2697), Two Rate 3 Color (RFC 2698), Time Sliding Window 3 Color Marker (RFC 2859). The source_address and destination_address can be both an IPv4 or IPv6 address, in IDL:

```idl
struct IPv4_address {
    unsigned long address; // 4 byte address
    octet mask; // netmask size(bits)
    unsigned short L4_port; // layer 4 port
    octet protocol; // layer 4 protocol
}

typedef octet IPv6_addr[16];

struct IPv6_address {
    octet IPv6_addr address; // 128 bit address
    octet mask; // netmask size
    unsigned short L4_port; // L4 port
    octet protocol; // L4 protocol
}
```

A typical connection setup scenario might look like this: a user in domain 3 wants to start a videoconferencing session with a user in domain 1 and requests his LNC (by means of e.g. RSVP, CORBA, ...) for an end-to-end connection. The LNC knows from its routing information which peering LNC CORBA object it has to contact. The latter looks up its routing information (typically this routing information will be gathered from the Border Gateway Protocol, BGP) to know which outgoing
i_connection_setup.DiffServ object in the core domain it has to contact, which will in turn contact the LNC$_{DS}$ of domain 1. Each LNC performs Flow Admission Control (FAC) (IP is inherently connectionless, so Connection Admission Control (CAC) is a bad term. However, there is always a concept of flow, which means a stream of closely related packets, e.g. for a videoconferencing session,) and configures the necessary edge and/or leaf routers for its Layer Network. In case of an underlying network (client-server relationship) which has to be configured to cope with the new connection, e.g. in case of the access feeder networks, the underlying LNC$_{OFN}$ has to be contacted which will take care of the configuration in its Layer Network (Fig. 4).

Figure 4: End-to-end connection management within the HARMONICS project with Hiperlan/2 as an example of a last mile technology

### 4.3 Optical feeder resource management

Future PONs, of which the main advantages are the simple maintenance and low cost [15], should be able to cope with many different classes of traffic. Therefore, the HARMONICS optical access feeder Layer Network is controlled by three entities (Fig. 4):

- LNC$_{OFN}$ which takes control of the configuration of the HARMONICS edge and leaf routers and which converts the IP addresses to ONU numbers before forwarding new requests to the RM.
- Resource Manager (RM) which has a link-oriented control of the OFN.
- Medium Access Control (MAC) which has a packet-oriented control of the OFN.

The RM performs the flow admission control for the OFN by accepting/rejecting new prioritized flows (best effort is handled by dynamic permit requests by the ONUs) according to the QoS, the available resources and the requests received from the LNC$_{OFN}$. The RM communicates the allocation of resources needed for the prioritized flows to the MAC, which performs the actual assignment of wavelength channels and time slots. The
interface i_connection_setup;
enum relation {federation, interworking, clientserver};
struct conn_setup_iface_ref {
    i_connection_setup iface_ref;
    relation type;
    string peer_technology;);
typedef sequence<conn_setup_iface_ref> conn_setup_list;

interface i_boot_up {
    conn_setup_list get_conn_setup_iface(in any address, in string peer_technology);}
interface i_connection_setup {
    void register(in i_connection_setup peer_lnc_ref, 
in any peer_address, 
in string peer_technology);
    boolean tear_down_connection(in unsigned long flow_id);
    typedef sequence<unsigned long> flow_id_list;
    void release_connections(in flow_id_list flows); );
struct BandwidthDescription {
    string Type;
    unsigned long Rate;
    unsigned long BurstSize;
    unsigned long Interval; );
interface i_connection_setup_DiffServ : i_connection_setup {
    unsigned long setup_connection(in any source_address, 
in any destination_address, 
in BandwidthDescription min_bandwidth, 
inout BandwidthDescription wanted_bandwidth, 
in octet DSCP); );

Figure 5: LNC_DL IDL interfaces i_boot_up and i_connection_setup_DiffServ

link-sharing mechanism could be applied to control the sharing of the PON by different 
classes of traffic. This traffic can be mapped into a hierarchical structure [16]. At the top 
level there is the link that has to be shared by different traffic, which in our case is one 
wavelength at one WDM link. Several ONUs share this wavelength through the power 
splitter of LSC 3 (Fig. 1). Each of these ONUs has multiple customers connected, each 
customer having several applications with different QoS requirements.

The problem is how to allocate bandwidth among all the kinds of traffic. The proposed 
solution consists of two allocation types: a pre-reserved allocation and an adaptive allo-
cation. The former reserves a certain bandwidth for each kind of traffic of each customer 
connected to the PON.

The flows’ pre-reserved values can be modified based on statistics of the traffic gen-
erated by each customer (which can be done at the RM based on regular feedback sent 
by the MAC about the real BW used). Because the real demand distribution for the link 
won’t be always the same as the pre-allocated one, adaptive allocation of bandwidth is 
activated, which means re-assigning any remaining bandwidth to traffic types that request 
more bandwidth than already reserved to them for the setup of new connections.

In order to perform bandwidth allocation, the RM receives a connection request from 
the LNC_OFN similar to the one (setup_connection) shown in Fig. 5 but with ONU 
identifications instead of IP addresses. The BW_{peak}, BW_{min} and the DSCP will determine 
whether this connection can be merged in the pre-allocated BW of this kind of traffic and
if necessary, how much bandwidth has to be adaptively allocated. Of course, this adaptive allocation will be closely related with the reshaping at the leaf and edge routers and with the MAC wavelength and timeslot assignment.

5 Implementation and Field Trial

To validate all the different parts, two lab trials (one embracing the optical components: OLT, ONU’s, AWGs, … and one comprising the higher layer management components, the L3 routers and the last mile networks) will be organized starting from May 2002 within the HARMONICS project. These lab trials will result in a field trial in Berlin and Darmstadt, Germany with real users, a VDSL and Hiperlan/2 last mile network and a.o. some videoconferencing and Video-on-Demand services (Fig. 6) starting November 2002. For the second lab trial and the field trial the Optical Feeder Network and the MAC protocol will be emulated on one or more PCs running Linux and the Click Modular Router software [17].

Figure 6: Lab and field trial setup

For the lab and field trials, the HARMONICS edge and leaf routers and DiffServ routers are adapted PC based routers running Linux and the Click Modular Router software [17] and equipped with Gigabit ethernet network cards. Fig. 7 shows the results of preliminary tests with a DiffServ core router loaded with EF and AF21 streams on one input port, BE and AF11 streams on another input port all heading for the same output port and this for a load varying from 10% of the link speed (here tested on 100 Mbit/s) to 100% (for both streams together on one input port).

6 Conclusion

This paper described the generic network architecture and a generic end-to-end QoS resource management framework applied to a DWDM access feeder network as studied
in the HARMONICS project. HARMONICS aims at addressing two challenges: (i) convergence of today’s access networks by providing a common dynamically reconfigurable fibre-based infrastructure feeding a wide variety of last-mile customer-access networks, and (ii) the increasing demand for more capacity, pushing fibre deeper into access networks, closer to the customers.

To tackle these issues, a novel DWDM based Optical Feeder Network (OFN) (Section 2) and an end-to-end connection management framework (Section 4) are designed, providing end-to-end QoS by using IPv4/IPv6 DiffServ at layer 3. At layer 2, a novel MAC protocol (Section 3.2) is proposed for the HARMONICS OFN, supporting both timeslot and wavelength allocation while guaranteeing QoS. The QoS mapping between DiffServ and the OFN is described in Section 3.3. For the last mile networks, advanced technologies as VDSL or Hiperlan/2 which support QoS, are used but their layer 2 QoS and the QoS mapping are not addressed in this paper.

The connection management framework is able to generically support a very wide variety of network technologies, both in peer-to-peer as in client-server relationships, not only restricted to optical networks as demonstrated in this paper.

Further work includes completion of all components and integrating them in a testbed to investigate the performance and scalability. Finally, a field trial experiment will demonstrate the feasibility of end-to-end connectivity with guaranteed Quality of Service using packet switching in the OFN.

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References


