Fast Wavelength-and-Timeslot Routing in Hybrid Fibre-Access Networks for IP-based Services

Kees Steenbergen, Fons Janssen, Jeroen Wellen, Rob Smets, Ton Koonen

Bell Labs, Lucent Technologies Nederland B.V.

P.O. Box 18, NL 1270 AA Huizen, The Netherlands

Email: steenbergen@lucent.com

The exploding demand for (IP-based) services in customer access networks, the demand for Quality-of-Service differentiation, and the demand for local loop unbundling can most efficiently be met by deploying multi-wavelength techniques in hybrid fibre access networks. In the IST HARMONICS project, a novel network architecture is being developed in which fast wavelength-and-time switching is implemented with optical gates to enable packet-based QoS-aware medium access protocols. A field trial is planned with VDSL and POF as the last-mile media, in the Berlin-Darmstadt network of Deutsche Telekom.

Introduction

The rapid growth of the internet has lead to an increasing demand of capacity in the backbone, metropolitan area networks, and presently also access networks. Due to the low sharing factor in access networks, cost aspects play a crucial role, even more than in metro networks. At the same time access networks are characterised by a huge variety in service classes, signal formats, and transport media: copper twisted pair networks for telephony, coaxial cable networks for CATV distribution, wireless GSM and DECT networks for mobile telephony, etc. These factors form a real challenge to create a cost-effective solution for the provisioning of broadband access.

The digging costs form a major part of the total investment costs. As a consequence, reuse of installed base in combination with a fibre feeder network upgraded with WDM, has been considered as a low-risk graceful approach to deliver broadband services to the subscriber. This has lead to new technologies for transporting high data rates over existing networks, such as xDSL over twisted pair [1], and OFDM or CDMA to conquer impairments in COAX and wireless networks [2].

Due to its wide-spread usage, the Internet Protocol (IP) has become the universal customer gateway. However, present-day implementations of IP only support best-effort Quality-of-Service (QoS). For simple email or web browsing this is sufficient. However, best-effort is simply not good enough for new real-time applications such as voice, videoconferencing, etc, which require low cell-transfer delay, delay variance, etc. For today's IP networks over provisioning is the only way to get to some kind of end-to-end QoS. Efficient mapping of layer 3 protocols such as IP onto various physical layer topologies, while maintaining guaranteed QoS, is a huge challenge. The IST project HARMONICS (Hybrid Access Reconfigurable Multi-Wavelength Optical Networks for IP-based Communication Services), focuses on an innovative dynamic wavelength-routing technique in the fibre feeder network, under control of a centralised network resources manager, in order to improve the flexibility in capacity provisioning. Capacity may be delivered on demand to network locations with heavy traffic offerings ('hot spots), even without prior knowledge of these hot spots, thus making the network forecast-tolerant with respect to the evolution of traffic patterns (see Figure 1).

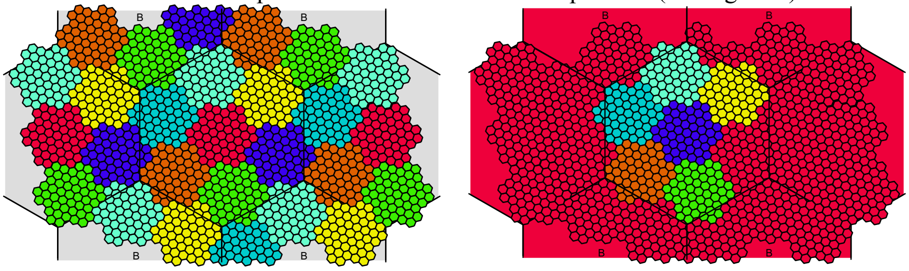

Figure 1: Spatially varying traffic demand. Uniform capacity distribution (left) and non-uniform capacity distribution (right) with hot-spots in the centre.

Earlier theoretical work has shown how flexible wavelength assignment to the ONUs may considerably reduce the probability of system congestion [3]. However, in order to optimally exploit the power of wavelength routing for network reconfiguration, a novel Medium Access Control (MAC) protocol is needed, which deploys both the wavelength and time domain in a shared fibre feeder network. The HARMONICS project devises such a protocol, which also takes QoS aspects into account when assigning wavelength and time slots. Thus various service classes in IP-based traffic can be efficiently transported, and the fibre feeder infrastructure can support a wide variety of last-mile customer access networks. This contributes to the overall project objective of supporting the convergence of networks.

System Architecture

Figure 2 shows the general network architecture of the HARMONICS project. The architecture consists of a centrally located Optical Line Terminator (OLT), a tree-and-branch fibre network, Optical Wavelength-channel Selectors (OWS) and Optical Network Units, connected to a number of last-mile access networks. The OWS consists of a WDM demux, a fast-switchable SOA array, and a WDM mux. The optical network consists of three optical splitting stages (LSCs), where wavelength selection is performed after the second splitting stage, thereby offering only a single wavelength to the ONUs. Location of the OWS at LSC-2 offers the optimum position between network flexibility and WDM equipment costs. The ONU acts as a fourth splitting stage, connecting a number of subscribers via the last-mile access network.

Communication between different domains, e.g. the core network, is arranged by the central local node controller (LNC) and is based on service level agreements (SLA). The central LNC interacts in the HARMONICS domain with the LNC for the fibre feeder network and LNCs for the last-mile network. The LNC of the fibre network communicates with the adaptive resource manager (ARM) for bandwidth reservation in the fibre feeder network. The medium access control (MAC) arranges the connection on the physical layer between the OLT and the ONUs.

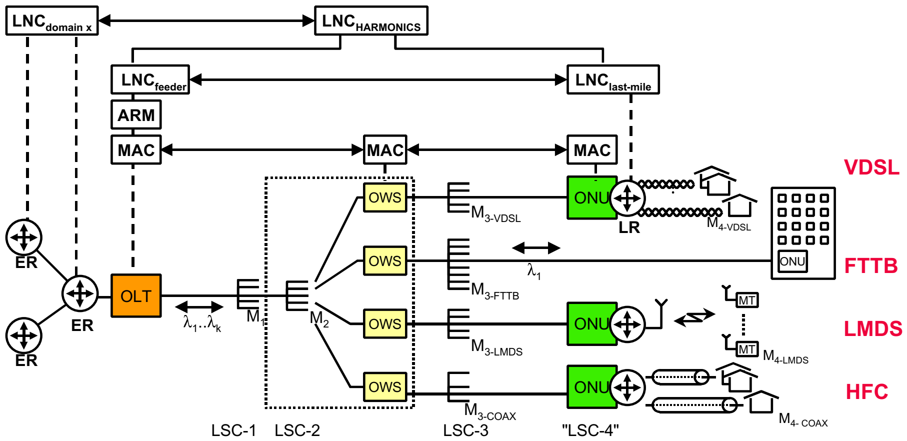

Figure 2: Network Architecture of HARMONICS. $M_1 = M_2 = 8$, $M_3 < 16$, $M_3M_4 < 50$, Downstream: 1.25 Gb/s per λ (<16 λ's), Upstream: 625 Mb/s per λ (<16 λ's), Maximum bitrate per subscriber: 25 Mb/s / 12.5 Mb/s, number of subscribers: 3200.

Wavelength and Time Slot Allocation

The Wavelength and time slot allocation scheme is visualised in Figure 3, showing the packets neatly ordered in time and wavelength domain. To detect the packets within the wavelength/time grid, it is necessary to keep a gap between the packets, both in time and wavelength domain.

Maintaining the packets at the right wavelength channel can be assured by either accurate temperature control of tuneable lasers located at the ONU, or centralising the generation of multi-wavelength continuous wave sources at the OLT in combination with remote modulators at the ONU location. The wavelength gap between the channels remains fixed and for straight-forward demultiplexing the wavelength channels can be used, since the spectral efficiency is very low and high-quality HDWDM filters are available at the market.

The alignment accuracy of the packets in the time domain is effected by the ONU-OLT distance (ranging accuracy), timing jitter of the transceivers, and dispersion. Due to temperature variations in the fibre and different distances between ONU and OLT, the round trip delay time between ONU and OLT will vary. Although this is only a slow process, active feedback is needed to keep up with the changes. Timing jitter can be limited by the use of an accurate PLL at the ONU. Dispersion results in transit time differences among the various wavelength channels.

Finally, the time gap is also used for switching between the wavelength channels. In order to keep the overhead of the gap low, it is necessary to remain below a few ns, requiring fast optical switches for which SOAs are being deployed in the HARMONICS architecture.

Figure 3 shows a fixed time slot allocation scheme for the packets in layer 2, which simplifies switching from one wavelength channel to another. For ATM cells - thanks to its fixed packet size - there is no mapping problem between layer 3 and layer 2. Using variable packet lengths, as is the case for IP packets, a more complicated time slot allocation mechanism is required. One solution is using fixed time slots and distributing long IP packets over several time slots. It may happen that an IP packet is also distributed over several wavelength channels, which needs to be taken into account when reassembling the complete IP packet at the receiver location.

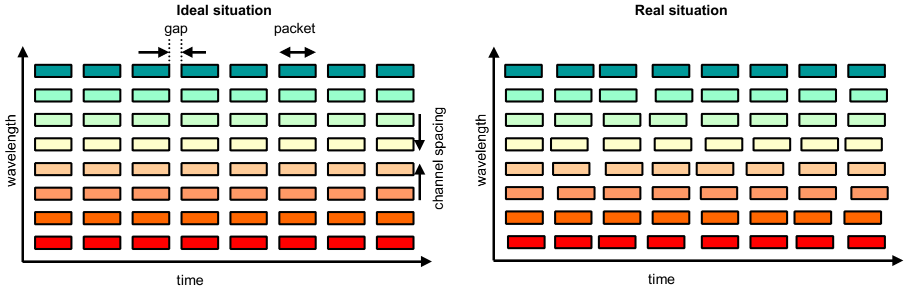

Figure 3: Wavelength and Time slot Allocation. Ideal situation without jitter (left) and real situation (right).

Disconnecting QoS classes from the actual wavelength channel simplifies the task for the Adaptive Resource Manager (ARM). The ARM only needs to assure the agreed bandwidth between the ONUs and the OLT and has the flexibility of multiple wavelength channels to meet the bandwidth requirements. Which wavelength the ONU will get is no longer an issue, as long as it gets its timeslots in time to meet QoS requirements such as cell delay variance.

Conclusions

The HARMONICS network concept proposes fast wavelength routing in combination with a novel MAC protocol for a fibre feeder network for various last-mile access technologies. The MAC protocol utilises flexible wavelength and time slot allocation to improve the efficiency of access. Decoupling of the QoS from the actual wavelength channel allows for simpler resource management to meet the end-to-end QoS requirements set by real-time applications.

Acknowledgements

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[1] IEEE Communications magazine, March 2000.

[2] J.S Leong and A.W.L. Janssen, "Comparison of OFDM, CDMA and TDMA Techniques for Interactive Services on Cable Networks", 13th Kabel Congres 1997, Den Haag, the Netherlands.

[3] Ton Koonen et al., "Advanced Optical Techniques in Fibre-Wireless Networks", ECOC proceedings, TuB1.2, Nice, Sep. 26-30, 1999