Exploration Programmes:
Corporate Technology Explores Future Telecommunications

Expected Cost Savings in Optical Networks

Wavelength Division Multiplexing (WDM) is widely used by operators to meet the continuously increasing bandwidth demands in the transmission network. However, the success of a new technology is not only dependent upon its technical features but also on economic aspects. WDM systems have an initial cost level due to the first installation of optical multiplexer and demultiplexer equipment. In this article it is shown that after only a few ten kilometres the WDM solution becomes more profitable than the deployment of SDH systems on parallel fibres. A small network example shows that an optical layer reduces SDH transport costs. Optical architectures are more profitable than pure SDH or even SDH over point-to-point WDM.

Exploration Programme "Transport Network Evolution" elaborates scenarios for optimised use and consolidation of the backbone transport network. The main topic is the economic migration of the network from the voice into the data world. Special emphasis is on the introduction of an optical transport layer and the optimised use of the client layers SDH, ATM and IP. The choice of the needed layers depends on the service portfolio to be offered and has a strong impact on the investment and operation costs of the network, and the flexibility to introduce new services.
With Exploration Programmes Corporate Technology is exploring telecommunication technologies and new service possibilities within projects having a long-term focus of 2–5 years to build up expertise enabling active business innovation support.

Network operators are increasingly adopting WDM as a cost-effective transmission technology in order to meet the bandwidth challenge. WDM is at a first glance primarily a means to boost capacity in the network without

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the need for installing new fibre cables. Hence, today's operators apply WDM primarily in point-to-point applications but the potential of WDM could extend far beyond this. The catchwords are optical networking or all-optical networks. Today there is a strong drive to use WDM not only as transport means for SDH but also for other client signal. The main interest here is on ATM and IP transmission over WDM.
Articles in newspapers and communication magazines promise that optical networks provide virtually infinite capacity at infinitesimal cost, which of course sounds very attractive. However, the reality is not (yet) there. The aim of this report is to give first indications on what seems to be realistic in the near future (five years) and points out where the barriers are. Another goal is also to provide techno-economical estimations as the success of a new technology is not depending only on its technical features but also the economic aspects have to be superior compared with the present situation.
It is renounced to give a comprehensive technical background of the WDM technology, instead it is referred to the relevant refs. [1–6].

Cost Savings in WDM-Based Networks

There are basically three different domains for cost savings by using WDM networks.

– The idea of WDM is to substitute fibres by wavelengths (WLs), see also figure 2 and figure 3 in [1]. Parallel transmission systems do not have to be guided through parallel fibres, but one single fibre is enough. Furthermore, optical amplifiers (OAs) substituted electrical repeaters. Thus by simply "counting boxes" an economical comparison can be made.
– As optical transmission is naturally an analogue technology any type of client signal can be transmitted. This allows bypassing some of today's network layers. For instance, IP could in principle be applied directly on a WDM channel without passing through the ATM and SDH layers. The WDM technology therefore allows hardware cost savings for the skipped layers.
– In today's layered networks we face the fact that communication is protected on several different levels, both on the transmission/provisioning level as well as on the application level. WDM allows introducing simple protection in the transmission layer, independent of the client signal that is carried. This means WDM would with one method provide protection routing for SDH, ATM, IP, etc. Such a unified protection scheme would reduce costs in the higher layers.

In the following possibilities one and three are discussed in more detail. For more information about the second alternative we refer to the article by Jean-Claude Bischoff in this ComTec issue, SDH: A Must, Luxury or Complication?

Programme Scenario
The basic lead question for the Exploration Programme Transport Network Evolution is how to provide a radically more cost-effective backbone network for supporting emerging multi-services markets.

Results

Cost Savings Due to Reduction of Line Equipment

Figure 1 shows a comparison of transmission systems (SDH 2,48 Gbit/s) operated

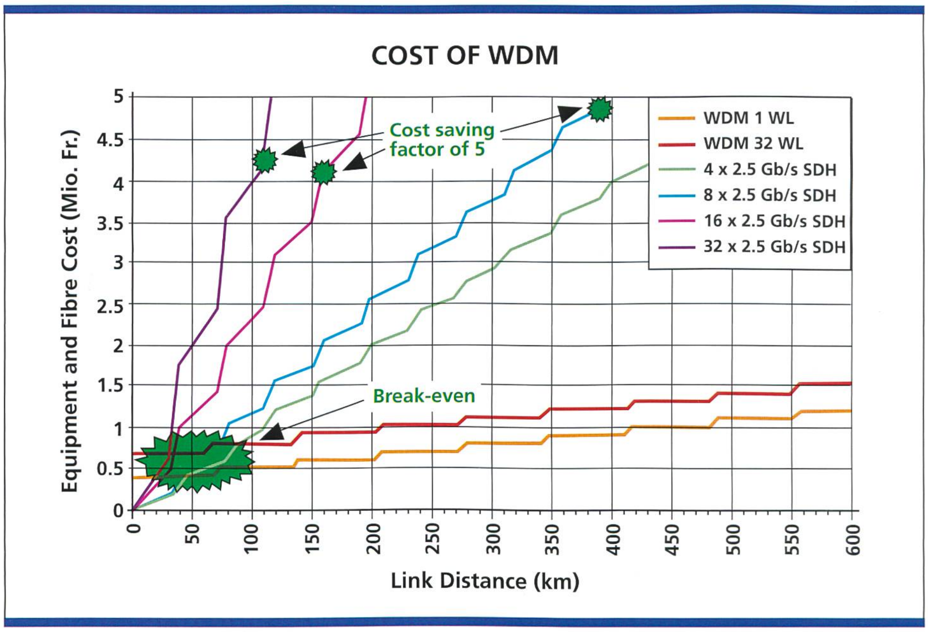

Fig. 1. Cost of WDM based transmission systems vs. systems based on parallel fibres as a function of the link length and the number of parallel systems (corresponding to the number of wavelengths).

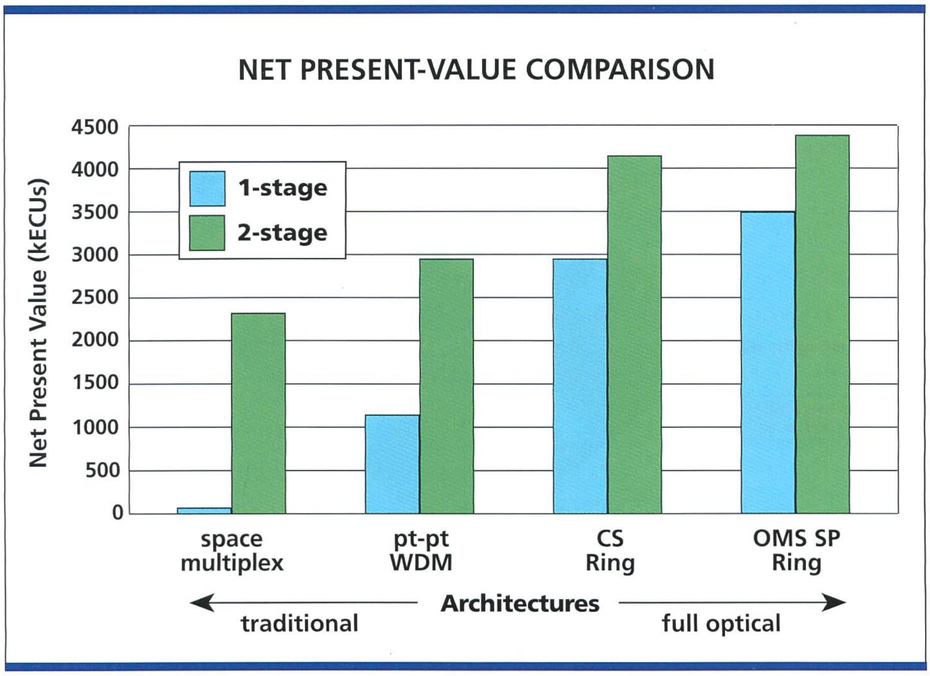

Fig. 2. Net present-value comparison of different architectures for a five-node ring. Implementation in one or two stages NPVs are shown relative to the solution with the lowest NPV, the 1-stage fibre multiplex solution (relative NPV 1).

on parallel fibres (fibre multiplex) using electrical repeaters and a 32 WL WDM system using one fibre and inline OA. The data used reflects market prices from October 1998. The case study includes optical terminal and transmission equipment cost (in one transmission direction only), fibre cost and the price difference between a standard, not WL-specific SDH interface and the more expensive WL-specific (coloured) SDH interface used in WDM. This price difference yields the two WDM traces in figure 1, where the lower bound is valid for one WDM channel and the upper for the fully equipped 32 WL WDM system. For the necessary cable upgrade in the fibre multiplex case, a 48-count fibre cable is assumed.

The most remarkable results are as follows:

- Systems installed with fibre multiplex (parallel fibres) have no fixed cost (fig. 1). The variable costs include fibres and regenerators.
- The WDM system has fix costs due to the mux/demux equipment needed from the beginning. Also the OA is partly a fixed cost, as it has to be designed for the maximum number of wavelengths. The variable cost factors are the optical inline amplifiers and the cost difference between plain and coloured SDH interfaces, but no additional fibres.
- Clearly there is a break-even point between the cost for parallel installed systems and the WDM solution for link distances far below 100 km.
- For practical distances in the present Swisscom core network (40–80 km between SDH nodes) the cost savings factor of WDM-based connections is in the order of 2 to 5, depending on the number of channels.
- Cost savings become even greater for larger distances bridged between nodes. This possibility can be exploited if the number of nodes in the Swisscom backbone network is reduced.

In cases where WDM is introduced in an existing cable with several SDH systems running over parallel fibres some or most of these fibres are relieved and can be used for other purposes, e.g. for fibre swapping with other network operators. The value of these relieved "fibre channels" is difficult to estimate since the value is dependent on many different factors:

- the number of relieved fibres;
- the place in the fibre network where the fibres are relieved;
- quality of the relieved fibres;
- traffic demand.

Cost Savings Due to Optical Protection

Optical networking (ON) is a rather loosely defined term. Some of the issues usually connected to ON are:

- transparency in the network, with respect to bitrate, data format, and "wavelength channels";
- large (close to infinite) bandwidth at any place and any time in the network;
- optical switching and optical cross-connects;
- large flexibility for the user;
- scaleable network;
- optical signal processing.

In a fibre the multiplexed wavelengths

SWOT ANALYSIS

Strengths	**Opportunities**
• better exploitation of existing fibre infrastructure • significant increase of available bandwidth in the network • WDM is a means to harmonise the transmission platform • scaleable network infrastructure (grow as you go)	• a decrease in maintenance cost as les electrical networking elements (repeaters) are deployed • WDM offers the possibility to move networking functionalities to the transport layer ⇨ cost reduction • free fibres for fibre swapping market • ready for unpredicted bandwidth increase
Weaknesses	**Threats**
• need to depreciate existing network technology • compatibility/convergence with existing network management systems is unclear • formation cost for planning and operation staff	• first installation cost • lack of relevant ITU/ETSI standards, thus follows possibly many proprietary solutions • Optical networing cannot live up to expectations

Fig. 3. SWOT analysis for the WDM/optical networking technology.

Abbreviations

ATM	Asynchronous Transfer Mode
IP	Internet Protocol
NPV	Net Present Value
OA	Optical Amplifier
ON	Optical Network, Optical Networking
SDH	Synchronous Digital Hierarchy
SWOT	Strengths, Weaknesses, Opportunities and Threats
WDM	Wavelength Division Multiplexing
WL	WaveLength

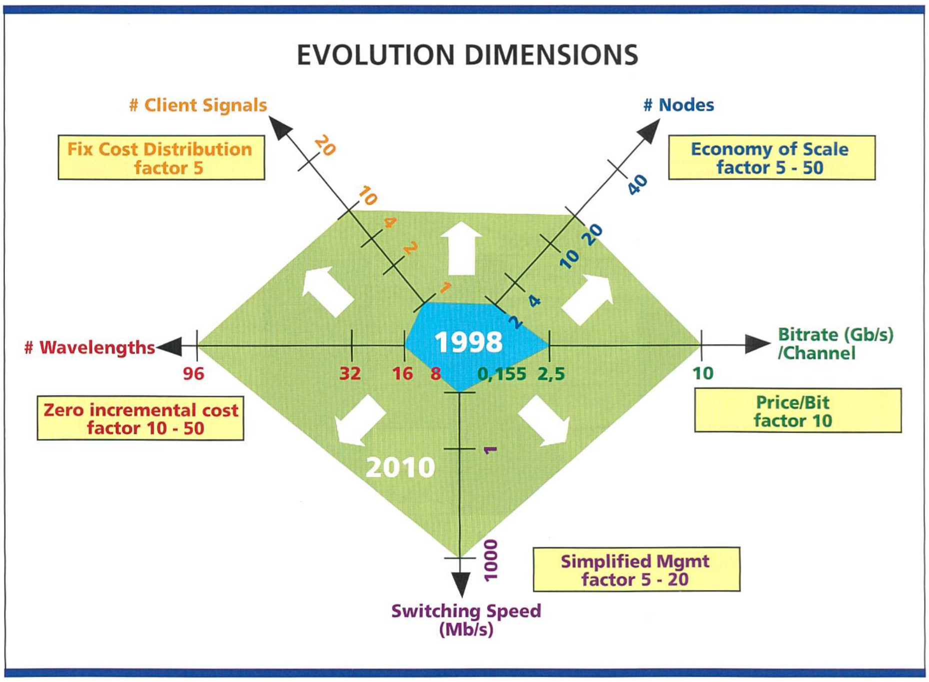

Fig. 4. Evolution dimensions in optical networking and potential cost saving factors. Please note that the indicated dimensions are not independent and, hence, neither are the given cost reduction factors.

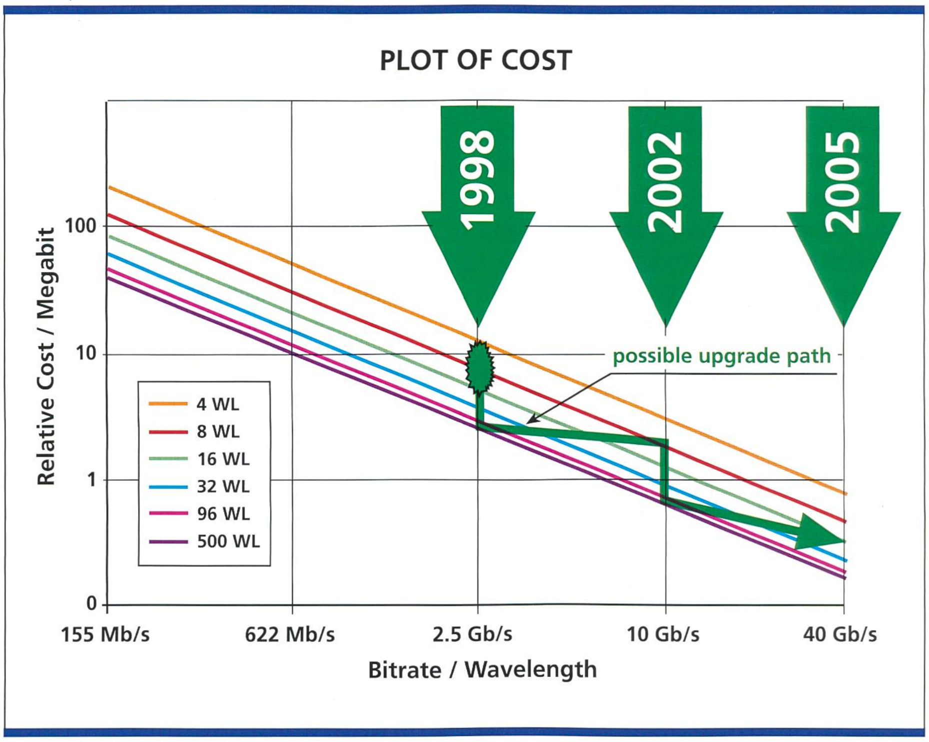

Fig. 5. Plot of cost per transmitted Megabit as a function of the bitrate per wavelength and the number of wavelengths.

do not interfere with each other and they can be manipulated individually. Therefore, at any place in an optical network (e.g. in a "optical node") the wavelengths can be separated optically and rearranged. Hence, this functionality of WDM enables optical add-drop multiplexer and optical cross-connects. These subsystems can then be used to introduce a completely new optical network layer into the backbone network. The new functions introduced by an optical network layer are

– optical WDM based routing;
– optical protection switching.

These new functionalities are the basis of ON. In the following a small network examples is investigated in order to compare optical architectures with the traditional SDH reference over fibre multiplex. The results presented here are based on the EURESCOM Project P615 "Evolution towards an optical network layer" [7]. The example chosen is a small, five-node ring with a node spacing of 10 km, and a of total 50 km. The traffic pattern is considered hubbed. This small network is a particularly tough test for WDM because the fibre and amplifier savings are relatively small. Competition will ensure that telecommunications prices will continue to fall over the coming decade; hence, an annual price reduction of 15% per year is assumed.

We further assume that the network is completely new and does not rely on any existing components. A single stage (the final network capacity is installed today in one step) and a two-stage investment scenario (the final network capacity is installed in two steps, today 40% and in four years remaining 60%) have been applied to a number of architectures, both a pure SDH reference architecture with fibre multiplex as well as a few optical architectures (for details of the architectures see [8]):

– SDH Multiplex Section Shared Protection Ring;
– SDH MS SP Ring over point-to-point WDM;

[1] Negative cashflows will be incurred when equipment is installed in the network. Positive cashflows will be generated by revenue and by the redeployment of equipment elsewhere in the network.

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- Coloured-Section Ring (an extension of a SDH ring with optical add/drop multiplexers);
- Optical MS SP Ring networks (here, the point-to-point WDM solution uses 16 channel mux/demux units).

The net present value[1] (NPV) is calculated for all eight solutions for a period of 10 years (the expected life span of the SDH and WDM hardware) and shown in figure 2 relative to the SDH 1-stage solution. This result shows that

- the optical architectures (CS ring and OMS SP ring) are clearly economically advantageous compared with the SDH and the SDH over point-to-point WDM solution
- it is beneficial for each solution to break the installation into two stages or phases. Further benefits might be expected if 3 or more stages were used. However, as the number of deployment stages rises, the cost associated with planning and executing each installation phase will tend to rise excessively. Therefore there will be an optimum number of installation stages.

From this basic study the OMS SP Ring solution is the most promising one, although this result may be misleading since the SDH cross-connects of this architecture were priced by interfaces rather than complete cross-connects.

What are the Potentials, Barriers, Pitfalls and Uncertainties of WDM and Optical Networks?

The answers to questions about potential, barriers, pitfalls and uncertainties are summarised in figure 3 in a SWOT analysis. As the concept of a WDM-based optical network layer (not simply point-to-point links) is still in its infancy – so far only research demonstrations are available and no field applications – the indicated uncertainties are real. Also, the prices used in figure 2 are estimated prices with a somewhat optimistic price evolution scenario. However, it is believed that the technical problems can be solved satisfactorily. The largest problem today seems to be the integration of the optical network layer into the network management system. A lot of basic research still has to be done, for instance within the frame of the recently started EURESCOM Project P918 where Swisscom Corporate Technology is one of the participants.

The strengths and opportunities of using WDM-based optical networks can be summarised with the headlines, clearly indicating the implication of WDM and optical networking:

- capacity demand is covered;
- capacity is cheap;
- a flexible network layer is available.

Outlook

The future evolution of WDM systems is closely related to the development of optical networks. Today, typically 8 or 16

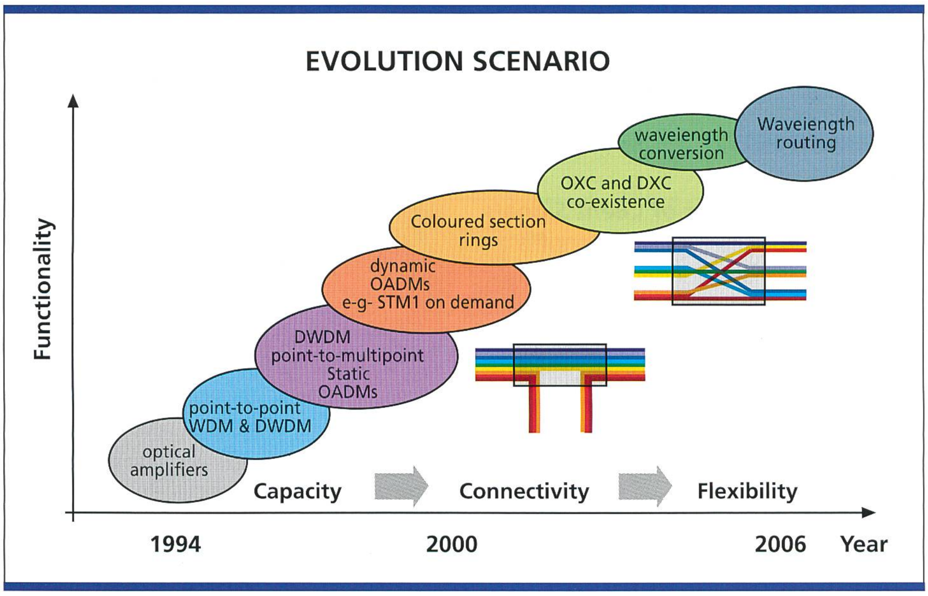

Fig. 6. Evolution scenario from amplified WDM point-to-point links to a wavelength routed network layer.

[1] Negative cashflows will be incurred when equipment ist installed in the network. Positive cashflows will be generated by revenue and by the redeployment of equipment elsewhere in the network

WL systems are deployed in Europe, up to 40 WL in the USA. Each WL is carrying 2.48 Gb/s. What are the next steps that can be expected realistically? Figure 4 gives an overview of the most likely evolution directions:

Direction 1: Number of Wavelengths per Fibre

The ITU-T recommendation G.692 [9] defines 41 WL for the Erbium doped OA with a channel spacing of 100 GHz. From a technological point-of-view, however, about 500 WL are feasible. An increased WL number means that even more WL than assumed in Fig. 1 could share the fix cost of optical terminal and line equipment. The price per WL would decrease up to about 50 WL. After this the price per wavelength saturates and the incremental cost per additional WL can almost be neglected.

Direction 2: Bitrate per Wavelength Channel

The commonly used bitrate in operators' core networks is SDH STM-16, i.e. 2,48 Gbit/s. In traditional SDH systems 2,48 Gbit/s are transported over one single fibre. In WDM based SDH systems, each wavelength carries 2,48 Gbit/s. There are systems available on the market with 5 Gb/s and 10 Gbit/s. In research, however, 20 Gbit/s and even 40 Gbit/s [10,11] have been successfully demonstrated. The "price per WL" discussed above can be translated into "price per bit" by allocating a bitrate to each WL (fig.5). Obviously, the price of a Megabit capacity decreases exponentially with increasing bitrate. For wide area network applications and short-haul communication, even 100 Gbit/s to 200 Gbit/s are envisaged by means of optical time division multiplexing systems [12].

Direction 3: Number of Client Signals

As mentioned above the wavelengths in a multiplex signal are independent and can in principle carry any type of client signal. Today the main client is SDH, but this situation is changing rapidly. One of today's hottest combinations of technology terms is "IP over WDM". Suppliers have already announced products with coloured optical interfaces. In single WL channel point-to-point systems such switches/routers can communicate directly to each other; in a network they have to be fed into the optical multiplex signal via transponders in order to guaranty optical network element management compatibility. In such a way, WDM enables operators to install independent networks in parallel on the same fibre by using defined wavelength sets for each network. Applying various client signals directly to the WDM layer offers enormous cost savings as many intermediate transport protocols can be avoided.

Direction 4: Switching Speed of Optical Space Switches

Today's available optical space switches are based on a variety of different technologies:
- thermo-optic switches;
- electro-optic switches;
- mechanical switches.

The mechanical switches have switching times on the order of 10 ms, thermo-optical ones in the order of 1–5 ms and electro-optical ones in the order of 1–10 ps. However, up to now, electro-optic switches have fewer gates than the other two types.

Direction 5: Number of Nodes in an Optical Network

Today's point-to point systems have only two nodes. This direction is obviously the way towards real optical networks. Cost savings in the order of a factor of 5–50 are expected due to economies of scale. A widely accepted evolution scenario of optical transmission and WDM based networking technology is depicted in fig. 6. The horizontal axis indicates the time, but also the development from a pure means for capacity upgrade to the flexible network layer. The vertical axis indicates the increasing functionality that is introduced into the network.

Conclusions

WDM systems produce an initial fixed cost due to the necessary optical multiplexer and demultiplexer equipment. But after only a few ten transmission kilometres the WDM solution becomes more profitable than the deployment of SDH systems on parallel fibres. The situation improves further for an increased number of wavelengths. Moreover, introducing a WDM-based optical layer will reduce SDH transport cost. Optical network architectures are more profitable than pure SDH or even SDH over point-to-point WDM. However, point-to-point WDM systems are useful in some circumstances as a cost-effective mile stone be-

Zusammenfassung

Transportnetz wirtschaftlich gestalten

Die Wellenlängenmultiplex-Technik (WDM) wird von Netzbetreibern vorwiegend zum Zweck der Kapazitätssteigerung im Transportnetz verwendet. Eine WDM-basierte optische Netzschicht beinhaltet aber auch grosses Potential, das Transportnetz wirtschaftlicher zu gestalten. Um einer technisch guten Lösung zum Durchbruch zu verhelfen, bedarf es daher auch wirtschaftlicher Vorteile im Vergleich zu existierenden Systemen.
Der vorliegende Bericht vergleicht WDM-basierte SDH-Systeme mit traditionellen, über parallele Fasern installierten Systemen. Es wird gezeigt, dass WDM-Systeme trotz Fixkosten der optischen Multiplexer- und Demultiplexerausrüstung bereits nach wenigen Kilometern wirtschaftlicher sind, als herkömmlich installierte Systeme. Für typische Übertragungsdistanzen im Fernnetz von Swisscom lassen sich Kostenersparnisse in der Grössenordnung von einem Faktor 5 erzielen. Am Beispiel eines kleinen Netzwerkes mit fünf Knoten wird gezeigt, dass voll-optische Netzarchitekturen im Vergleich zu herkömmlichen Varianten wirtschaftlich vorteilhaft sind. Zum Schluss wird das Entwicklungspotential und die Tendenzen der WDM-Technik diskutiert. Es zeigen sich fünf Richtungen ab, in welchen deutliche Leistungsverbesserungen zu erwarten sind: vergrösserte Anzahl Wellenlängen, gesteigerte Bitrate pro Wellenlänge, weitere Client-Signale neben SDH, schnellere optische Schaltelemente und schliesslich der Übergang von Punkt-Punkt-Systeme hin zu optischen Netzen mit mehreren Netzknoten.

fore introducing full WDM networking. If feasible, the investment in new networks should be done in a number of discrete installation stages or phases, such that the capacity rises in each stage to cope with the steadily increasing demand.

The evolution of WDM technology is expected along five directions, each of them providing considerable potential for cost savings. The most important one is the transition of point-to-point systems to real optical networks with many nodes. It is expected that the technical problems, e.g. with the integration of the optical network layer into the network management system, can be solved to satisfaction. 9.4

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