Invest in Sweden

# Photonics Systems

# Roadmap 2005-2010

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# 1 Executive summary

The wire line operators are facing interesting challenges and opportunities the coming years. The traffic is growing at a very high rate, almost doubling every year. Internet “best effort” traffic dominates in volume but also data traffic with quality of service, QoS, requirements are growing. Legacy traffic as voice circuits, leased lines etc need to be supported also in the future. At the same time revenue per bit are falling dramatically, especially for the best effort segment where prices are several orders of magnitude lower than for other services..

To meet the challenge several incumbent operators have started to discuss “Next generation network”, all IP/ router based and introducing Ethernet in transport and switching. Photonics systems are supporting this trend with a family of “Next Generation” products as NG-SDH, NG-WDM and OXC, Optical Cross Connect, which are much more adapted for data traffic. Activities in “Transparency”, i.e. using the wavelength layer more efficient and avoid unnecessary opto-electrical conversions and that way save capex and GMPLS/ASON, Automated Switched Optical network, that will make the network much more flexible and save opex will be key areas the coming five years.

The number of broadband subscribers are growing with impressive 50% per year, probably the fastest growing segment in telecommunication today and even if the majority is DSL and cable modems, more and more will be based on fiber access, FTTx. That is due to the higher requirements for Internet access speed but also for the introduction of services like IP- Telephony and IP-TV, i.e. triple play over broadband. In the future the broadband access will support e-government services as e-health, e-learning etc and a number of local and enterprise services. The broadband network will be a true multiservice network based on IP and Ethernet, the latter still not meeting the full transport carrier-class requirements

The convergence between telecom, datacom and media network means that several major standardization bodies are involved and in the future common standards will be more addressing the interworking issues. Triple play is also discussed for the mobile network and a common service platform can be seen as one step in the convergence between fixed and mobile, followed by roaming between the networks and a common implementation of the future fixed IP based infrastructure.

Sweden was early to use Internet and broadband. We have however lost some momentum the last years due to lack of overall strategy. What characterizes Sweden is that the government support for fiber built out and the deregulation has created a lot of operators in broadband, 20 national and 59 local, and a very competitive situation with low prices but very fragmented.

The Swedish Photonics industry is also fragmented. Most of the system suppliers are start ups by earlier employees at Ericsson and Telia, which have substantially reduced their operation.

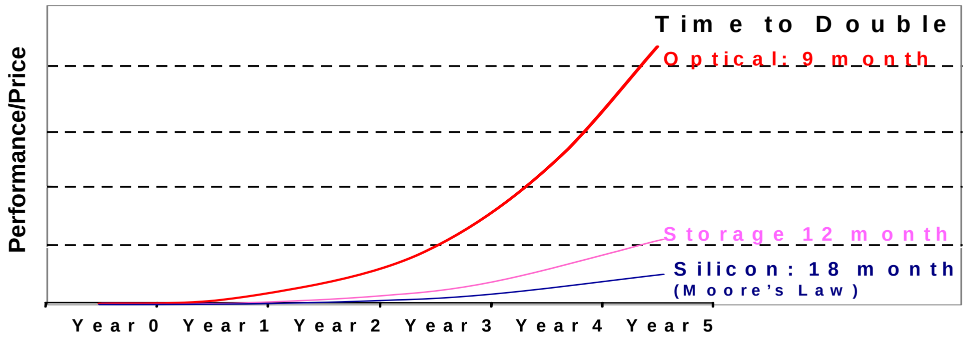
From international perspective the companies are small niche players but with interesting technology Sweden has opportunities to improve its position in broadband and in Photonics systems. Competitive advantages are our IT maturity, willingness to explore the broadband society, the open network concept supported by government and our competence in the photonics area both in system and research. The convergence between fixed and mobile where our strength in mobile can be utilized and the strong growth in broadband can be vehicles. This market has just started!

*The study has been performed by Örjan Mattsson, representing pioneering experience of decades of photonics systems business and technologies spanning over several life cycles of systems and services.*

# 2 Introduction and History

It is now about 25 years ago that commercial Photonics System, or Fiber Optics Systems, was introduced as transport vehicles in the backbone telecommunication networks. The main reason was the high bit rates and the long repeater distances, which made the Photonics System, very cost efficient and attractive.

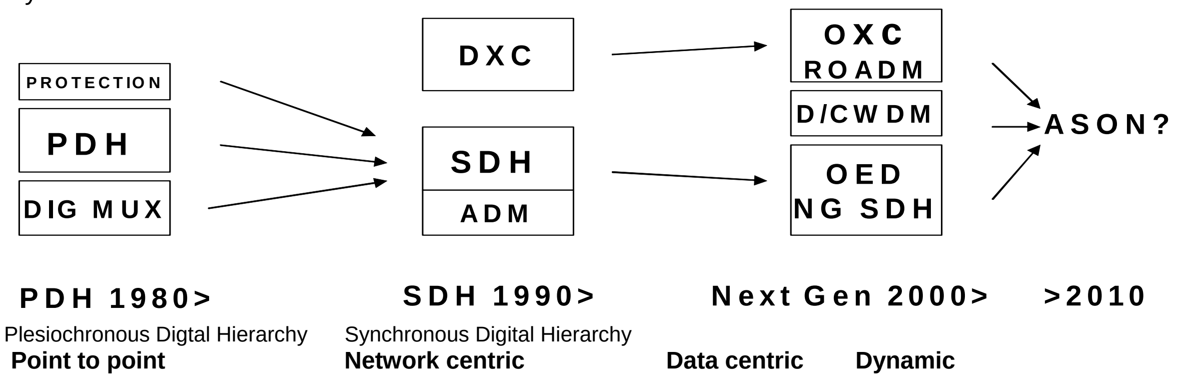
Improved transmitter and receiver components and fibers with better characteristics have improved the merit of Photonics systems measured as bit rate x repeater distance. The improvement factor is even better than the well-known Moores law valid for integrated circuits. As one example every new installed optical submarine system in the Atlantic has had a capacity higher than the sum of the preceding ones.




The success of Internet and world wide web had not been possible without the cost efficient network capacity that photonics has been offering allowing people at a very low cost surfing to websites all over the world. The same goes for long distance call, the globe has virtually been shrinking and this has changed and is changing the business models for operators.

Due to lower system cost the Photonics System started in the 80-ies to move into the short haul part of the network. New requirements as being able to build protected mesh and ring networks compared with the earlier point-to-point meant that the old generation PHD systems were replaced in the beginning of 90-ies by the new SDH/ Sonet hierarchy which offered a much better network flexibility and protection. The DXC, the Digital Crossconnect Connect were introduced for bandwidth management.

In the second half of the 90-ies the WDM systems entered the market. One reason was to overcome the speed limitations in electronic processing and instead create a number of parallel wavelengths to further increase bit rate, another reason was the increased flexibility that the creation of a new lambda layer could offer.



During the last years there has been a rapid growth of Internet traffic and data is now the dominant service type. Existing SDH, more optimized for voice and circuit switching is gradually been replaced by Next Generation Systems offering much more data centric service aggregation and packet switching. Examples of products are OED (Optical Edge Devices) including next generation SDH, NG-SDH, Optical Cross Connect system and Metro DWDM and CWDM. The features of these systems will be explained later.

Future steps will be to introduce automated network management and create an automated switched optical network, ASON/ GMPLS, and optical wavelength transparency.

Another focus area will be to design flexible, low cost and robust metro- and access systems to handle the growth of broadband subscribers and broadband capacity.

# 3 Overall Trends

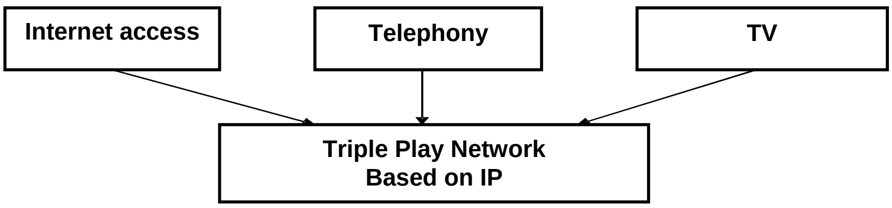
The major general trends that will impact the future wire line communication network and that way the roadmap for Photonics systems are

- data becoming the dominating type of traffic, the introduction of triple play and in general a multiservice network based on IP
- the fast growth of the number of broadband subscribers combined with higher access speed per subscriber
- the convergence between fixed and mobile
- The open network concept, sometimes referred to as multioperator network. A Swedish concept but increasing interest from abroad.

## 3.1 Multiservice network based on IP

Internet traffic has shown consistent growth over the past 20 years, more than doubling each year. In year 2000 the Internet traffic volume in the backbone network surpassed that of voice traffic. The communication network must handle even more aggressive capacity growth as Internet now is dominating in volume and continues to grow with 75–100 % per year. This is more than double compared with the traditional QoS type of data traffic, mostly enterprise related, and the voice traffic volume is almost flat. Carriers need to double their capacity every 18 months compared with their earlier growth of 10-20 % per year. At the same time the revenue per bit is falling dramatically, around 50% per year, making the cost per bit many, many orders of magnitude lower than for traditional voice and GSM.

One way to handle the situation is to add new types of traffic with higher revenue, which means converging the different networks for Internet access, traditional telecom and media distribution into one IP based network, the **triple play network**. The prerequisite is of course that the market is deregulated in that respect.




## 3.2 Broadband subscriber's growth

As a consequence of the growing use of Internet the number of broadband subscribers is increasing rapidly. With the definition of broadband being speed higher than ISDN, i.e. 128 Kb/s and always ON, the number of broadband subscribers globally was at the end of 2004 150 Million with the impressive growth rate of 50% per year which makes it one of the fastest if not the fastest growing segment in the telecom industry today. The majority of these lines are DSL, 63% and the rest is cable TV modem except for a small percentage of fiber access and radio.

The FTTx connections at the end of last year was almost 3 Million and start to grow faster than the overall bradband market. Sweden has due to the early investments done by Bredbandsbolaget, B2, the majority of the fiber accesses in Europe today.

Countries like Japan and South Korea has ambitious implementation plans for fiber access with access speed of 100 Mb/s. In Japan the growth of fiber access subscribers today exceeds the DSL and the target in Korea is to have 10 million subscribers with 100Mb/s access speeds 2010. In US the RBOC Verizon will invest 10-20 BUSD the coming 10-20 years to introduce fiber access to every household in their network.

The broadband access will be the future bearer of all communication services to and from the home being Internet, telephony, TV and all other multi media services. That means higher requirements on speed, real time, security, etc. In the near future 100 Mb/s symmetrical seem to be a reasonable target figure.

## 3.3 Fixed – Mobile convergence

Another convergence discussion is between the fixed and mobile network, which can take place on different levels as

- Services and service platforms
- Roaming with session continuity
- Common network resources both metro access and core

On the service level the triple play services are used both in fixed and mobile network meaning that data, telephony and TV all are supported. This will open up for common service platforms and other common tools.

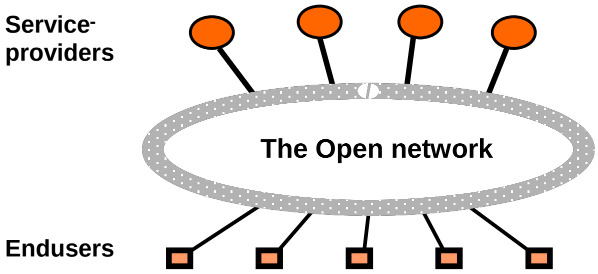
Another logical step will be to introduce roaming between the networks, for example a data call shall hitless be transferred between the fixed and mobile network when you leave your office and want to continue your PC activity when on the move.

The digital radio networks as GSM and UMTS are based on digital transmission and already today the backhaul part of the infrastructure network is common for carriers offering both fixed and mobile services. The trend to bring new cost efficient technologies into the metro network that supports quality of service and scalability will drive the common parts of the network further out to the edges and eventually the radio network except for the access part will be part of the same general fixed IP based QoS network.

In South Korea the government has initiated a massive program, BcN ”Broadband convergence Network” with the aim to implement and drive standards for a converged triple play fixed and mobile network.

## 3.4 Open Networks

From a user perspective that is a desire to select for every service the service provider that offers you the most attractive conditions independent of operator. On the other hand it is a desire for the service provider to reach any customer/end user. This is the thinking behind the “Open Network” concept or the “Operator Neutral/ Multioperator” concept. What it requires is a separation between the roles of service operator and network operator.




This concept has its origin in Sweden, very much driven by the government as it stimulates competition and growth and enables public services more easily be offered over the broadband network. It is now a growing interest for the concept from abroad. It put special and more stringent technical requirements on the network from standardization and harmonization point of view.

# 4 Applications and Services

The future broadband network will migrate from being an Internet access to be a true multiservice network based on IP where triple play, i.e. Internet access, IP telephony and IP TV, can be seen as the foundation.

Different services have different requirements on the network and it must be possible to prioritize between them. Internet access is a best effort service that is differentiated by its access speed. VoIP has requirements on QoS especially turn around times and IP-TV on real time bandwidth, jitter, multicasting capability and service encryption. Network security, IPv6 addressing scheme are capabilities that enables VPN (Virtual private network) tunnels and support enterprise services and public services like healthcare and e-commerce.

## 4.1 Examples of end user services to be supported by the future broadband fixed network

### *4.1.1 Private Sector*

- Internet access, more than 10 Mb/s, future 100 Mb/s symmetrical
- IP- telephony and picture phone
- IP- TV, bandwidth per channel 5-10 Mb/s (MPEG2), multicasting
- Video on Demand, unicasting
- IP- HDTV, bandwidth per channel 10-20 Mb/s (MPEG 2/4)
- Interactive games
- Intranet access, 10 Mb/s high security for connection to company LAN
- Public Services as e- government, e-health, e-learning
- Local channels and information services

### *4.1.2 Enterprise sector*

- Triple play
- LAN interconnect, GbE and MbE
- SIP based communication VoIP, messaging, etc
- ATM, connection oriented packet service, non IP
- Ficon , Escon, Fiber channel, storage network
- VPN, Virtual private network layer 2 and 3
- Video Conferencing QoS nx Mb/s

### *4.1.3 Public Sector*

- Same as Enterprise sector
- E- government services, QoS based on triple play
- E-health services, QoS based on triple play
- Information channels to households
- Connections between schools, hospitals and other authorities

### *4.1.4 Network services*

- Secure tunneling
- Peer-to-peer (file sharing)
- Peering
- Nomadic access

# 5 Networks: access, metro and core

## 5.1 General

The general trends as explained earlier i.e. Internet best effort traffic is growing rapidly but does not generate corresponding revenue, significantly growth of broadband customers and IP convergence between tele, data and media have changed the operator market. New operators without any legacy network are entering with new system solutions and many incumbent telecom operators have been forced to announce plans for ”the next generation network”, sometimes with an almost revolutionary approach closing down their existing circuit switches and having the whole network based on routers and packet switching.

Due to convergence there are several networks standardization committees involved, the major being ITU-T for telecom, IETF for Internet, IEEE for Ethernet, DVB, Digital Video Broadcasting for TV distribution. In the future that will not be one single standard as 3G instead the common part will be around interoperability.

The network trends can be summarized as

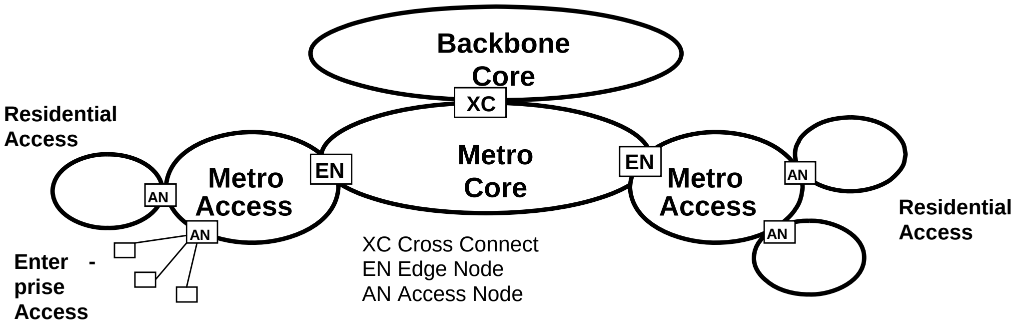
- The future network will be IP and packet based .The goal is convergence and layer reduction, avoiding overlay and adjunct networks and that way achieve simplification, flexibility, scalability and cost reduction
- The future network is a multiservice, converged multimedia network carrying different services as best effort Internet traffic, critical high revenue quality of service traffic and legacy services. One issue is how much of the network can be common to both best effort and QoS services.
- Ethernet, due to its low cost potential and wide spread usage in the enterprise sector will migrate substantially into the public access and metro aggregation network. Ethernet is however still lacking carrier class properties in transport.
- Connection-oriented packet switching using labels, MPLS, will be used to deal with critical QoS IP services which can not be handled by connection-less operation or simple over provisioning. There will however still be need also for traditional circuit switching
- Introduction of Next Gen Optical Network Products which can cost efficient handle both TDM and packet traffic but work together with and reuse existing legacy equipment. The market value of today’s SDH equipment is 100 BUSD.
- More advanced management system with added intelligence in the optical layer will enable remote and automated network configuration to reduce opex and shorten provisioning times. Common control plane with the IP layer will in the future enable automated switched transport/ optical network.
- Network transparency i.e. using the lowest network layer needed. Wavelengths should be processed electrically only when required, that way capex reduction with 65 % in some domains has been demonstrated.

The telecom network can in a very simplified way be divided into the access, metro and core networks Sometimes metro is defined as the metro access or aggregation network and a separate core part. In this report the metro core part together with the backbone network constitutes the core network.

Access network: Critical regarding capex and opex as every cost is per subscriber but the network is on the other hand well defined from user and service perspective and no migration issues.

Metro network: From architecture point of view the most complicated part of the network being an aggregation network for all subscriber services with different quality of service requirements. These services shall in a cost efficient way be fed to appropriate operator and service connections in the core network.

Core network: Involves interesting challenges both regarding architecture especially in the metro core part of the network and technology in the long distance network where capacity in the "pipes" is key to drive backbone transport cost down.




*Simplified view of the communications network*

## 5.2 Access network

The dominant broadband access technologies today are DSL and cable TV modem. The access connections are terminated in DSLAM:s at the access nodes. The reuse of existing infrastructure means certain limitations. With higher speed the distance for DSL will go down substantially. ADSL2+, for speed up to 26 Mb/s covers distances in the order of 1-2 km depending on cable and for VDSL offering 50 Mb/s, the distance is around 300 meters and increasing cable fill factor can create cross talk problems.

Introduction of triple play means higher speed requirements and has triggered a more aggressive built out of fiber based access. The fiber access, being FTTH, FTTB, FTTC or FTTN (home, basement, curb and neighborhood) is using basically two types of architecture, point to point (P2P) and point-to-multipoint (P2MP). The latter is also denoted PON, passive optical network and the earlier AON, active optical networks. In Europe AON is the dominating technology and preferred due to a greater flexibility for new services and upgrades. In US and in Asia PON is chosen because it is a more cost efficient technology, especially in areas with private houses, typically common in US.

Also in Europe some carriers are looking into long reach PON, maybe with amplifiers, to get rid of all active equipment in the access network. There exist different architectures for PON system where some use a special fiber or alternatively a separate wavelength for TV.

Both single and multimode technology is common in the FTTX systems and 1- or 2-fiber solutions. The trend is towards using single mode to get longer distances to the access node and that way cover a bigger area.

From cost point of view the FTTx systems are quite competitive in urban areas, especially the FTTB/C/N systems. For the rural areas digging is a big issue. Fixed radio access is here an alternative and two new technologies have created interest. One is the TDD version of UMTS that have been used as Internet access in several rural areas in Sweden. The other is the Wimax technology, still unproven but with some interesting data regarding speed coverage and mobility.

Another important radio technology is WLAN, which is used primarily in cities and hotspots like airports and similar places and there offers Internet high speed access. The standard is moving very fast to enable higher speed, bigger coverage and better quality including voice. The business models are still an issue. Fixed line broadband, WLAN and 3G is an interesting combination for creation of seamless always best connected broadband.

ATM was earlier the transport protocol both for the private and enterprise access networks but there is a clear trend to move over to Ethernet/ LAN technology. Due to high volumes and strong price pressure Ethernet has become a very cost efficient technology and IEEE standards now exist for 10/ 100 Mb/s (FE) and 1/ 10 Gb/s (GbE).

Among the different broadband access vendors there are both supporters of layer 2 technology using VLAN to distribute services to the end users and supporters of layer 3 technology using the “normal” IP addresses, both have its pros and cons.

### 5.3 Metro network

The Metro access or aggregation network connects access terminations like DSLAM:s or their fiber equivalent OLT:s at the access nodes to edge nodes located on the core side of the network where the payloads are separated and rearranged by routing and switching depending on service classes and service operators. The metro network can be run as a layer 2 network with traffic aggregated in Ethernet switches or as a layer 3 network using aggregation routers.

The transport in the Metro access network is handled by Optical Edge Devices, OED:s, of many different types. For residential broadband access the client interfaces are of type Ethernet or ATM. For enterprise applications, where the OED:s often are located at site, they support services like Frame relay, Mb and Gb Ethernet, Escon, Ficon and Fiber channel for storage applications and leased lines E1/E3. On the server side the OED:s have Ethernet transport or SDH interface. In many cases the switches and routers have optical Ethernet ports and use simple point-to-point connections to edge nodes.

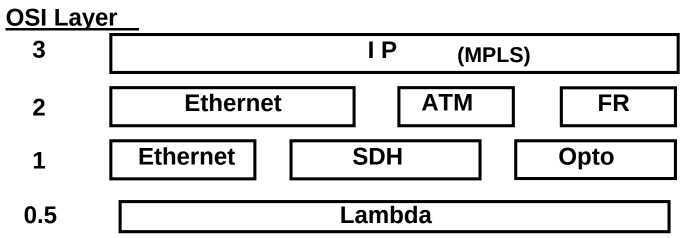
From pure transport point of view the metro network constitutes normally of a number of physical rings based on for example SDH or of mesh type of network with built in protection.

Specialized protocols, as Resilient Packet Ring, operates over SDH rings and offers certain transport features. From cost point of view it is of interest to use Ethernet also as transport protocol but there exists no standardized carrier class Ethernet transport today.

In the metro access rings CWDM equipment can be used, in many cases with integrated layer 2 transport switches. Usage of WDM offers easy upgrade of capacity by adding new wavelengths. It also gives higher flexibility including lambda access, which can be offered to big customers, and enables service separation i.e. different wavelengths for different services.

## 5.4 Core network

Even if almost all services in the future will be packet IP based, they have to meet different requirements from Internet best effort to critical enterprise services that even could be based on ATM or Frame relay, streaming video, mobile backhaul and legacy services as today's voice.




As can be seen from the OSI stack there are many alternative layer 1 and 2 solutions to handle layer 3 IP traffic. For best effort traffic the simplest is connectionless switching and over- provisioning using Ethernet for layer 1 and 2. The QoS type of services requires a connection oriented solution and in some cases for bulk layer 1 traffic even circuit switched end-to-end solution using SDH or WDM/ Opto. Ethernet is today not interesting as transport layer 1 technology for core network as it is not yet meeting the carrier class requirements even if it exists several proprietary OAM solutions and multiplexing schemes. In the future a standard will certainly be established.

An IETF standardized connection oriented solution for IP traffic exists today using MPLS protocol over Ethernet for label switching. It is a more cost efficient technology than ATM or Frame relay. The IP/MPLS links can provide carrier class connections for QoS services and be engineered the optimum way bypassing not involved routers and switches. The IP/ MPLS traffic can use Ethernet (with the limitation on QoS mentioned above), SDH or Opto (OTN Optical Transport Network) as transport layer 1 technology. The OTN transport layer is part of the next generation optical products which can map data packets directly on wavelength.

There is a strong need to make the network more dynamic and remotely controlled in the future to improve flexibility, network redundancy, shorten the provisioning times and overall reduce opex. Automated transport solutions are addressed by ITU-T in their ASON, Automatic Switched Optical Network, architecture and by IETF in their proposed standard GMPLS which expands MPLS by introducing a common control plane covering layers 0.5 (lambda) to 3. The usage of GMPLS can become an organisational issue as it involves both the "IP" organization and the optical transport.

Probably the most "heavy" transport circuits will be handled independent from the IP traffic. One example could be a Nx10 Gb/s WDM ring engineered separately and connecting all core routers while the finer transport granularity, 2.5 Gb/s and less are optimized and protected together with the upper network layers using GMPLS.

For Internet traffic, 50-80% of the node traffic is typically pass-through. By adding transparency and avoid going through transit routers/ switches or doing unnecessary opto-electrical conversions specific wavelengths carrying through-traffic can remain in the optical domain. The boundaries of "these islands of transparency" are at nodes where all wavelengths are converted into the electrical domain because traffic reaches a boundary between two networks or at interface between incompatible equipments. By introducing transparency, substantial cost savings can be achieved for the operator

The backbone network has been characterized by a demand for increased bit capacity to reduce transport cost. Higher and higher electrical bit rates and due to speed limitations in electronics WDM is used to create a number of optical channels in parallel. It has been possible to more than double system capacity every year. During the “bubble” period a lot of overcapacity was built into the network due to many new operators entering the market. This situation is still valid in many cases why demand for systems with even higher capacity is quite low. The commercial introduction of 40 Gb/s systems per lambda is however expected 2007.

# 6 Photonics systems

## 6.1 Drivers for next generation systems

The design of the Next Generation Photonics Systems is based on

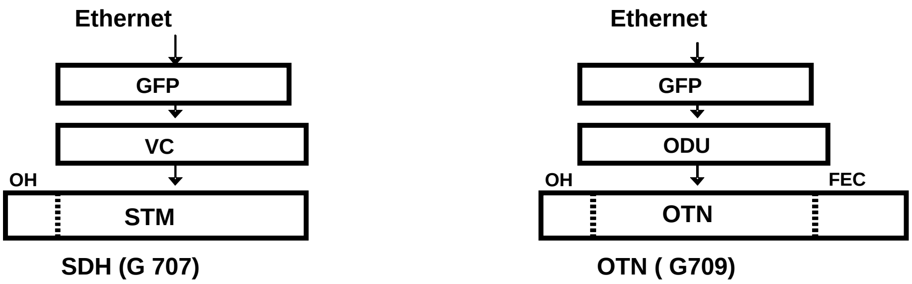
- More efficient handling of packet based traffic, especially Ethernet
- More dynamic and remote control of network resources, including lambdas.

Next Generation Systems comprises OED(Optical Edge Devices) including NG-SDH, OXC ( Optical Cross Connects) with both optical and electrical switching fabrics, ROADM ( Reconfigurable optical add/drop multiplexers) and Metro WDM, both DWDM and CWDM. Of course there will still be a market for the legacy products SDH, DXC (Digital Cross Connect), ADM (Add Drop Multiplexer) and Long Haul WDM

## 6.2 Mapping of data frames, GFP

To meet the demand for a more efficient transport of data, ITU-T has standardized a number of important technologies

- Generic Framing Procedure (GFP) offers efficient mapping of many data services including Ethernet into SDH frames for example 2x1GbE streams into a 2.5 Gb/s, STM 16 frame. Together with Virtual Concatenation (VCAT) and Link Adjustment Scheme (LCAS) the SDH infrastructure can offer a variable transport bandwidth.
- OTN, Optical Transport Network, a new frame structure in parallel with SDH/STM, which can map data directly on a wavelength via ODU, Optical Data Units and that way establish an optical transport layer. It is combined with a powerful forward error correction scheme, FEC.




## 6.3 OED, Optical Edge Devices

It is a wide family of products that belong to the OED category, everything from simple media converter to NG-SDH, next generation SDH. Being multiservice devices they are designed with different options regarding interfaces, both on client and server side, and optional functionality as switching fabrics, routers, multiplexers and WDM. As being cost sensitive OED:s is optimized for different applications as indicated below.

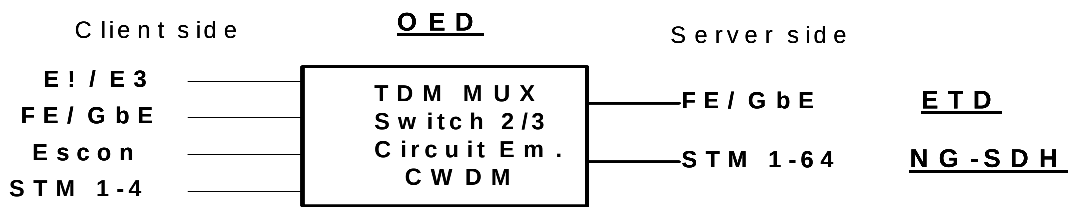
<u>Media converters</u>
Simple low cost devices that can provide point-to-point Ethernet connection or connection to a small switch or router. They are in principal transparent for any Ethernet service but can do some simple prioritizing and fault management...

ETD, Ethernet Transport Device

Ethernet Transport Devices are based on packet switch architecture and the TDM traffic is typically carried out through circuit emulation. Uplink connections are normally of type GbE. ETD offers often some carrier-class provisioning for Ethernet transport but first when that is fully standardized there will be a real market take up for ETDs

NG-SDH, Next-generation SDH

90% of the OED market is today NG-SDH products. By using GFP protocol Ethernet is efficiently mapped into STM frames and NG-SDH will offer a carrier class transport with protection and all other features associated with SDH. At the same time it gives the benefit of reuse of intermediate legacy SDH equipment.  On the server side STM 1-64 interfaces are supported including colored WDM laser and in the future also STM 256, i.e. 40 Gb/s.




## 6.4 Bandwidth provisioning :  OXC, Optical Cross Connect and ROADM, Reconfigurable Optical Add Drop Multiplexer.

Control and switching functionality is fundamental for dynamic networks to redirect capacity. Two main networking elements can fulfill this role,  Optical Cross Connect, OXC or the lower functionality product, the reconfigurable optical add drop multiplexer, ROADM.

There are three possible Optical Cross Connect variants

- OEO-Based on electrical switch fabrics providing sub-wavelength grooming
- OOO-A photonic or electrical based switch fabric delivering transparent wavelength switching
- Hybrid- Combines the functionalities of  OEO and  OOO

To date the main benefit for carriers using OEO:s has been platform consolidation between subnetworks with different vendor equipments and different network layers.

By introducing a common control plane for OXC, SDH and WDM equipment the carriers can transit from a ring-based to mesh architecture. Adding an automated control plane results in further cost saving, since manual intervention is not needed and provisioning times are reduced and automated restoration is offered. By using the OOO version of OXC these features can be extended to the wavelength level. Some carriers have chosen a more decentralized approach and instead of using a central OXC they create a dynamic network with similar characteristics using a ring topology based on ROADM:s

Both the OOO with optical switching and the ROADM are from technology point of view rather immature products. Tuneable lasers and filters and robust switching elements are the critical components and they are expensive today and their reliability have to be proven. During the coming five years period the technology issues should be solved which can make the OOO:s based on pure optical switching and ROADM:s very interesting products. Carriers can expand their dynamic network to also include wavelength transparency.

## 6.5 Metro WDM

WDM, wavelength division multiplexing was introduced to increase the link capacity per fiber using "fiber multiplication" of SDH systems. It was primarily intended for the long-haul and ultra long-haul market point-to-point connections. By introducing intermediate add/drop multiplexers along the route a more flexible multipoint type of network were achieved.

The standardisation of the Optical Transport Network, OTN, frame that allows IP and Ethernet to be mapped directly on the wavelength and that combined with lower cost for transponders have opened up an interesting WDM market in the metro segment... Using WDM is not only a way to increase capacity but can also be used to separate services and operators by different wavelengths.

There are two basic WDM systems, the dense version DWDM using max 80 wavelengths and the coarse version CWDM using 8. In CWDM non-temperature stabilised lasers are used offering a lower cost product which can be of interest for low/ medium capacity metro access applications.

As in the long-haul version of WDM, OADMs are used to create multinode network often ring based. Typically Metro DWDM systems have a reach of up to 200 km, point-to-point or ring. In the future more and more ROADMs will be introduced for reasons as more flexibility, faster provisioning and automated restoration.

## 6.6 Long Haul DWDM system

What has characterized the long-haul market is the need for increased capacity which was met by the system vendors by higher bit rates and more wavelengths. Longer distances between repeaters and regenerations points added to reduce the overall transport cost. Besides the C band 1535-1565 nm the L band 1570-1620 is used to be able to double the number of wavelengths and also to handle dispersion shifted fiber. In connection with the bubble around year 2000 a huge overcapacity was created which the remaining carriers are still suffering from. Today there is no real drive for increasing system capacity including usage of L band The state of the art commercial systems today have modulation rate of 10 Gb/s, number of wavelengths 80+80 (C+L band with 50 Ghz spacing) i.e. a total capacity of 1.6 Tb/s. Repeater sections are 400 km and distance between regeneration of 6000km, that means coast-to-coast in US.

The next step in the STM hierarchy will be STM 256, i.e.  40 Gb/s that some major carriers have announced they will gradually start to deploy in the coming 2-4 years.

## 6.7 Market Outlook and Trends

During the "bubble period" 1998-2002 the Optical Transport market exploded peaking with 30 BUSD in sales 2001. It was followed by a steep downturn due to overcapacity and carrier debt. The bottom seems to have been reached and in 2004 the market for the Optical Transport products was around 10 BUSD, a 15 % increase from year 2003. The growth is mostly in the European market, followed by Asia while US is almost flat. The forecast from analysts for the coming 5 years is quite conservative partly because of the history and the estimate is a small increase in global market in the order of 5% per year with Europe as the main growth market.

The next generation products constitute almost 60% of the market and that will increase over the years. The multiservice metro aggregation network presents the greatest optical networking revenue opportunities as operators shift to next-generation network elements to support data service roll out and the increase in the number of broadband connections.

Some comments for the different system products:

- OED:s is 40 % of the total market, the majority ( 90%) being next-generation SDH.
- OXC is only 5 % of the market and has dropped in absolute value from earlier years but will recover over the period. OXC will probably take over the majority of the 10% market share that DXC has got today.
- ROADM:s will overtake the OADM market in 5 years period, i.e. around 20%.
- Metro WDM market share is around 10 % , growth rate 15%, somewhat higher than OED:s
- Pure CWDM is about 20% of the DWDM market and will probably stay that way.
- The Long haul DWDM market is about 10% and quite flat.

The market figures given above refer to Optical Networking products and not the broadband access equipment including FTTx products. It has not been possible to get these market numbers separated from DSL, cable modem, access switches and access routers etc. but the total broadband access market year 2004 was in the order of 8 BUSD.

# 7 Components and Technology

## 7.1 Modules, Tx/Rx

Today in the market there are mechanically standardized Tx/Rx modules for system speeds up to 10 GbE that can be directly plugged into transmissions equipment and routers. Lower speed examples are GBIC for 1 GbE systems and SFP, XFP (smaller size) for 2.5 Gb/s transport system. One can select between different receiver sensitivities and the modules can offer narrowband lasers with 100 GHz separation for DWDM applications.

Tunable lasers are of interest both for remote controllable add/drop systems ROADM, and to reduce inventory for DWDM systems. The tuneable components exist today, which can handle the whole or part of the C-band (1530-1565 nm) but they are too expansive and not life tested enough to be real commercial.  This will happen in the coming 5 years period. At least this is the opinion of that industry.
OEIC, opto-electrical integration in InGaAsP is still far away commercially, as too many incompatible process steps are required. Some kind of integration seems necessary to be able to design and implement 100 GbE modules due to speed constrains.

80 Gb/s with electronic clock extraction has been demonstrated.

For the lower speed and more access oriented applications, VCEL lasers are of interest because they are easier to produce with better yield than the edge emitting lasers. Today they are however available only as short wave lasers but there are a lot of effort to expand them into the 1.3 and 1.55, the latter wavelength is a real challenge.

## 7.2 Components

Fibergitter is used in photonics systems as filters and for dispersion compensation. Its usage as filters to add or drop WDM channels are established today. For CWDM with its lower requirements interference filters are the dominating technology as they can be produced much cheaper.

Tunable filters have existed in the lab for 5-10 years. Their main application is in remotely controllable ROADM:s . Commercial components are costly and can operate over rather few wavelengths but their price/performance will certainly improve over time.

For true optical cross connects other technologies are dominating as controllable X- switches and MEMS. With MEMS, micro electro magnetic switch, much bigger matrices can be built but reliability is still an issue.

Dispersion compensation is fiber based today but using gitter components are of interest due to much smaller dimensions. For the controllable dispersion compensation required in 40 Gb/s systems gitter technology is the only viable technology. In low volume production it is today possible to meet the system requirements over the whole C-band

## 7.3 Optical amplifiers

There are in principle four different types of amplifiers, Erbium-doped fiber amplifier (EDFA), Raman amplifier (RA), Erbium-doped waveguide amplifier (EDWA) and semiconductor optical amplifier (SOA).

The dominating type in use today is the EDFA. Due to the hangover from the bubble period with big inventories the interests in developing the EDFA technology has been almost dead for some years but this will change. The main trends will be miniaturization and cost reduction for the metro and access market and improvement of gain control for in particular reconfigurable optical networks.

Raman amplifiers are mainly useful for high capacity long-haul applications. However there are many issues as safety and long term stability because very high pumping powers, up to 1W.

EDWA is potentially a very low cost device because of its small size, the possibility for automatic manufacturing and single-chip integration of pumping sources and the passive components. Today EDWA shows low technical performance but development of new technology could lead to a cost reduction by one or two orders of magnitude.

Semiconductor optical amplifiers are potentially low-cost devices but are suffering from many drawbacks in technical performance as intersymbol interference, WDM channel cross-talk, increased noise figures and low output power. New technologies could give openings.

## 7.4 Technology

It can be worth mentioning that communication is 30% of the market related to optical technology and that most of the research activities are generic.

The overall issues with optical technology compared with electronics are

- the components are too big
- low functionality, lack of processing and memory capability
- too high cost due to low integration

On the other hand optics has very good characteristics in speed, sensitivity and low attenuation which makes it outstanding for transport applications.

To get around the problems associated with integration in InP, there are similar activities using quartz on silicon. Some promising results with integration of 32 lasers, detectors and WDM devices on a single chip have been demonstrated.

Two new areas have shown great potential even if no commercial product will come out on the market during the coming five years.

The first area is Photonic Crystals. With that material you can achieve very high Q-value with the potential to build compact narrowband filters, even negative refraction index (!) and other strange phenomena which can offer interesting applications.

The other area is Metallic Optics with potential to achieve real integrated optics, maybe even memory chips but it is still a long, long way to go.

# 8 The Swedish position

## 8.1 General

During the 1980-ies and the first part of 1990-ies Sweden had a strong position in fiber optics very much depending on the earlier Swedish model with a close cooperation between the government owned operator, Telia, the big system vendor Ericsson and some research institutes and universities, nowadays Acreo, KTH and Chalmers.

Today Telia is a private owned carrier with almost no research in this area. Ericsson has terminated their own development of Optical Transport systems. On the other hand many new small companies have been started, the majority by ex- employees of Ericsson and Telia and from academia. In competence Sweden is still strong in most areas but the whole photonics industry is now very fragmented and fragile, and can not afford to have their own research. The university and institute is still world leading in some areas, e.g. high speed modulation but financing and resources are an issue.
To create meeting places and coordinated efforts for all actors working with broadband products and services, the test bed concept have been created and supported by the government through VINNOVA. The biggest is Acreo:s national test bed where new products, technologies, applications and services can be tested end-to-end with real test pilots.

## 8.2 Market

In 1999 the government proposition "IT for all" was approved and initiated a massive deployment of fiber all over the country supported by public financing in the more rural areas. A number of city networks, around 200, have been created and most of them work according to the earlier described open network/ operator neutral concept. As it stimulates local initiatives, gives broadband the status of "4th utility" and opens up for competition by the service providers the concept starts to create interest in other parts of the world and in EU.

Especially Bredbandsbolaget, B2, was very aggressive building out FTTx access during this period and in 1999 50% of the Swedish broadband households were connected by FTTx (!) and still Sweden is leading in Europe in number of fiber accesses.

Even if Sweden have lost its leading position in the number of broadband subscribers Sweden still are an early adopter of new technologies like triple play, open network and have a much deregulated marketplace. It is a strong competition between ADSL operators primarily Telia, B2, Cable TV operators and the city networks, totally 20 national and 59 regional operators. For that reason Sweden has today the lowest Internet access prices in Europe and highest average access speed but in the long run a consolidation in the operator market must take place but still having the open network concept in consideration.

## 8.3 Suppliers

The Swedish system vendors are as mentioned earlier quite small from international perspective and are specializing in different market segments.

- Ericsson: Development of products in the broadband access area including FTTx. Sourcing all the optical transport products. Interesting to see Ericsson strategy in the future thinking of the convergence between fixed and mobile.

- Packet Front: Broadband access systems. Fast growing even abroad. Key feature is their provisioning system for open networks. Founders came from B2 and Cisco
- Transmode(+Lumentis): WDM systems. Strong in CWDM where they are nr 2 in size and in Metro WDM applications with built in OXC. Founders from Ericsson
- Net Insight: NG SDH product based on DTM technology which offers a granularity of 0.5 Mb/s and TDM multicasting. Strong in video transport. Founders have Ericsson and Academic background
- Wavium: OXC lambda switch based on electrical core with a powerful mgmt system. They have just been restructured, founders from Telia.

Hopefully these companies the coming years can benefit from the segment growth in broadband and triple play and that way grow and become profitable.

Added to the list could be all the companies working with radio based broadband products, services both for private, enterprise and public applications, companies working with IP-based Set Top Boxes, home networks etc and that way the list will be much longer.

There are a number of companies working with modules and components. The only ones with some size are

- Zarlink strong in VCEL and transmitters based on that technology
- Northlight part of former Ericsson Micro, active in transmitters and EDFA
- Proximion ,reconstructed and now focusing on gitters for dispersion compensation

There are many small start ups as Phoxtal, diplexer and bitable ROADM switch, InvOpto, low power, small size optical links even for home networks, Cernolux tunable OADM, Accilon, polarization and spectra meter and Syntune (part of Altitune) tunable lasers .

For these companies to survive a strong market support is needed as the Swedish market is too small.

## 8.4 Research

In the research field Acreo, KTH, their JV, KPRC, KTH Photonics Research Center and Chalmers are the centers for Photonics research.

Even internationally they are strong in their focused areas but struggling with getting money. The long term financing are lacking and there is a high risk that Sweden lose the competence in photonics that has been built up over long time. This is ironically when the real fiber optic market is starting.

In Kista, Acreo and KTH are strong in areas like high speed modulators, laser technology, gratings, packaging, optical amplifiers and basic research in photonic crystals and quantum optics. Acreo in Hudiksvall is focusing on fiber based research as specialty fibers, sensors and similar industrial applications. Chalmers has its main focus in high speed modulation, polarization mode dispersion and laser technology.

Acreo are looking into network architecture issues related to the demand from future broadband services and is also operating the earlier mentioned broadband test bed. A great numbers of Swedish vendors, operators and service providers are involved in the test bed and are doing tests around interoperability, end user perceptions, service requirements on the network, management etc. The test bed is a way to repeat the earlier successful Swedish model with cooperation between vendors, operators and academia. The Acreo test bed has attracted attention from international actors and can be seen as a way to create interest for Sweden in photonics and broadband.

# 9 Glossary

| | |
|---|---|
| **ADSL** | Asymmetrical Digital Subscriber Line - Modem to introduce broadband over a cupper pair used for telephony. |
| **AON** | Active Optical Network. Star network i.e. point to point connections from central node to the subscribers. |
| **ASON** | Automatic Switched Optical Network. Architecture for a network that can be rerouted and switched automatically. |
| **DXC** | Digital Cross Connect. Switching of PDH and SDH traffic for bandwidth management and network consolidation. |
| **FTTx** | Fiber to the x. x can be H home, B basement, C curb or N neighborhood. |
| **GFP** | Generic Framing Procedure. Standardized way to map data efficient into SDH and OTN frames. |
| **GMPLS** | Generalized MPLS. Protocols common from IP level to wavelength enabling automatic switched IP network. |
| **HDTV** | High Definition TV. TV with about four times higher resolution and bandwidth requirement than ordinary TV. |
| **MPLS** | Multi Protocol Label Switching. Standardized way to create connection oriented links in an IP routed network. |
| **OADM** | Optical Add Drop Multiplexer. |
| **ROADM** | Reconfigurable OADM. Devices that drops and inserts wavelengths in a WDM system, ROADM remotely controlled. |
| **OED** | Optical Edge devices. Common name for aggregation equipment in the access and metro network. |
| **OTN** | Optical Transport Node. Standardized hierarchy for IP over wavelength. |
| **OXC** | Optical Cross Connect. Switching of wavelengths and SDH traffic including grooming. |
| **PDH** | Plesiochronous Digital Hierarchy. First generation more transmission oriented standard for optical telecom system. |
| **PON** | Passive Optical Network. Tree and branch i.e. point to multipoint connections from central node to subscribers. |
| **QoS** | Quality of Service. Service that has requirements of type availability, bandwidth, delay, security etc. |
| **SDH** | Synchronous Digital Hierarchy. Second generation more transport and network oriented standard for optical telecom system. |
| **TDM** | Time Division Multiplexer. Every communication link has its fixed connection end to end in the network. |
| **VPN** | Virtual Private Network. Creation of a separate connection in a common network. |
| **WDM** | Wavelength Division Multiplexer. |
| **DWDM** | Dense. |
| **CWDM** | Course. Several wavelengths using the same fiber for capacity or separation reasons |

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