IMTECH TELECOM

HIGH LEVEL DESIGN

DESCRIPTION FOR SUNET

Preface

The purpose of this document is to give the reader an understanding of the basic concepts used in the OptoSunet network. When SUNET made the call for tender there were a couple of things the successful bidder (Imtech Telecom) had to relate to, for example fibre structure, routes, etc. SUNET also had a number of requirements relating to equipment and performance.

The first chapter in this document details these basic requirements and SUNET's objectives with building a Hybrid network.

The second chapter gives the reader a general overview of the building blocks Imtech Telecom used in the delivered solution to meet these requirements. Some of the performance limitations are also addressed in this chapter.

The third chapter addresses how the customers and services are connected and delivered. Some constrains in the solutions are also highlighted.

The fourth chapter gives the reader a high-level understanding of how new connections would be deployed. This is not to be confused with installation recommendations.

Stockholm, October 2008

Imtech Telecom and SUNET

Imtech SUNET

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1. Background to the OptoSunet design

Most national educational and research networks (NRENs) have recognized the value of converging from Leased Circuits to Dark Fibre Networks, and so has SUNET. One of the driving forces is flexibility in research projects to connect researchers within Sweden and globally. The Swedish university computer network – SUNET - wanted to upgrade its nationwide network connecting all Swedish universities and university colleges. The new network was given the name OptoSunet. TDC AB was awarded the contract to supply all fiber bonds. Imtech Telecom was awarded the contract to supply all active equipment.

The equipment tender covered the following:

- Optic transmission equipment.
- IP-routers.
- Technical maintenance services.
- Installation and deployment.

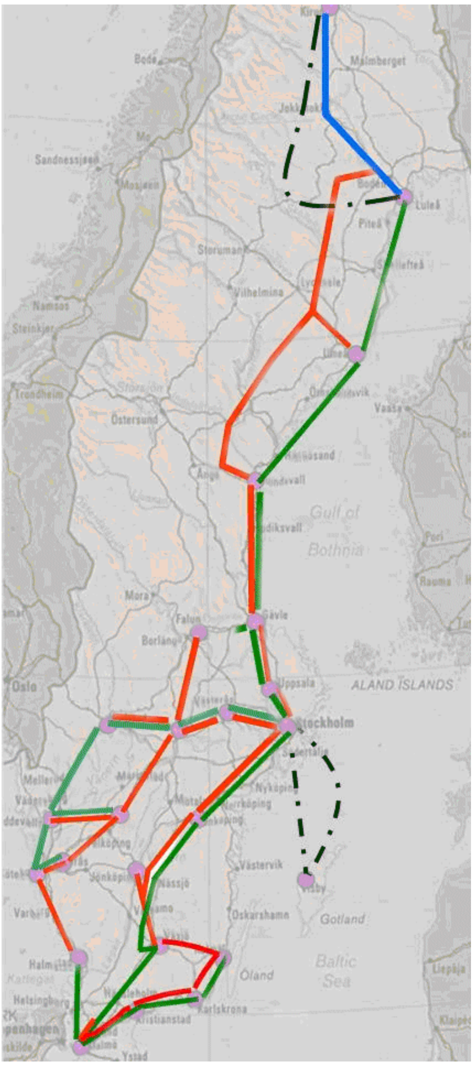
1.1 *General Prerequisite*

SUNET had the intention to build a network that apart from giving the user high capacity should also give high operational security and availability. The network should provide on-demand facilities when requested by the user. Since SUNET cannot assume that single fibre connections or single equipment always works there was a requirement for redundancy and diversity on both the fibre connections and the equipment.

1.2 Basic conditions for the Optical network

The red and green networks create necessary redundancy and diversity and carry 10 Gbit/sec point-to-point traffic. Both the red and the green networks are designed in such a way that amplifying nodes and dispersion compensations etc can handle up to 40 Gbit/sec point-to-point connections. However, the green network fibre has the best values and is therefore preferable to use for 40 Gbit/sec.

1.3 *Fibre structure*



SUNET has rented fibre in a star structure. The optical network is divided into three systems; north, west and south, where each system comprises of two networks; red and green. Each user is connected both to the red and green network for diversity and redundancy. The basic requirement was that the red and green fibre pairs should be separated by at least 10 metres geographically, to maintain availability in case a cable is severed.

Note that certain cities belong to more than one network, e.g. Borlänge is connected to both north green and west red. Also note that traffic decisions between red/green networks are made by the routers and not by the optical network equipment.

From Luleå to Kiruna there is only one fibre path (the Blue network). The backup route is a leased STM-16 from Kiruna to Luleå in a diverse path.

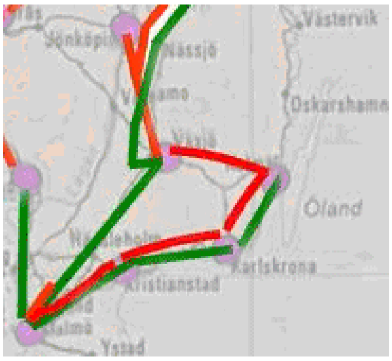
Two rented STM-16's are used for the island of Gotland in the Baltic Sea. These are connected to existing equipment at the university in Gotland and to two of the core routers in Stockholm.

All fibres and transmission links in the network (except for some local connections in Stockholm) are leased from TDC AB.

The network solution is such that an individual university in a town is not dependent on equipment placed at another university.

1.4 ***Special design considerations***

Due to the fact that there is very limited fibre availability in some parts of the country, some special solutions had to be implemented to maintain the demand. One example of this is the southeast part of Sweden, along the coast from Kalmar to Malmö:



Here, the red and green fibre pairs are actually located in the same cable. Due to the lack of alternative cables the 10 metre separation had to be abandoned. Instead the red and green networks in that part are laid out so that the red network can be considered as going clockwise, and the green counter-clockwise (even if the underlying topology is still a star topology). Thanks to redundant equipment at the PoP sites, availability can still be maintained, even if this single cable is severed. It does, however, cause some extra complications when designing p2p connections in this part of the network.

The link between Borås and Gothenburg is another example of where such cable sharing had to take place.

1.5 *Different customer handoffs*

There are two main different types of customers defined that are connected to the network; type A and type B. SUNET also identified a need for two different services, p2p (point-to-point) connections and LDGE (Low Density Gigabit Ethernet). Customers and services are described in the following sections.

1.5.1 Type A Customers

This covers the majority of SUNET's customers. These customers have 10 Gbit/sec from the core node in the city (both the red and green core nodes) to the university node in the university/college in that city.

1.5.2 Type B Customers

These customers have 2*1 Gbit/sec. These are presented from the core node in the city (red and green nodes) direct to the customer's network, meaning that for these customers there exists no university node in the optical network. These customers use existing local router equipment to connect to OptoSunet.

1.6 *Point-to-point connections (p2p-connections)*

The network is set-up for type A customers to establish a number of p2p-connections with 1GE, 2.5G or 10GE. It will also be possible to establish p2p-connections to Kiruna.

1.7 *Low density Gigabit Ethernet (LDGE)*

SUNET has a requirement to provide Gigabit Ethernet (GE) connections to other parties (Internet providers, peering points etc) in many places around the country, but only to a small number in each town ("low density"). In order not to waste optical channels unnecessarily, a solution was deployed whereby a number of GE-channels are transported in a 10 Gbit/sec-channel and are dropped at the different PoPs. The LDGE's are connected to the central router in Stockholm.

1.8 Requirements on routers

Basic requirements

SUNET were looking for an overall solution when it came to routing in the new network. All routing is consolidated to a central routing solution in Stockholm. SUNET's customers (the universities) are connected with customer premises-equipment (CPE). Type A-customers are included in this solution.

Many of SUNETs customers use their own (in certain cases private) AS-numbers and BGP for traffic exchanges with SUNET's central routers on redundant connections (and doubled equipment).

1.9 *Central router solution*

SUNET requested a central router solution. The solution should ensure that customers that are redundantly connected are never affected by traffic interruptions in case of errors in the central equipment or in one of the connections to the customer.

2 High level design of OptoSunet Hybrid Network

The OptoSunet network is designed in such a manner that three different sections of the long haul transport network converge in Stockholm. Each of these sections (North, West and South) consists of two redundant paths – Red and Green, so in the simplest terms there are six different CoreStream links converging in Stockholm. Along each link there are a certain number of PoPs that are designed to add/drop traffic to/from Stockholm. In most cases PoPs are configurable OADMs (COADMs), except Sundsvall and Karlstad PoPs that are Geo-Diverse Select OADMs (GD-SOADMs) on the Red North and Red West networks respectively. COADM PoPs are designed to add/drop only one band to/from Stockholm, while GD-SOADMs are more flexible and allow you to add/drop any lambda to/from Stockholm or any other PoP in the network.

The CoreStream system is an 80 channel, 50GHz spaced DWDM system, which operates in the conventional EDFA amplifier C-band, with the option to upgrade the system to 192 channels with no interruption of service. When the system is configured with all 192 channels for standard span designs, the capacity is at least 960 Gbps.

The CoreStream platform, used for the green and red core routes, supports 40G transmissions. The banded structure of the CoreStream system lends itself towards a mix of bandwidths and channel densities so that special technology is deployed only when necessary. The CoreStream system used for OptoSunet provides 10 sub-bands within the C-band, each of which can be deployed with the technology required. To enable a lower start up cost whilst meeting the initial requested channel counts, Imtech Telecom proposed the use of 50 GHz spaced 10G channels, with up to 8 in each band. The network has been optimized with a full upgrade to both 40G and up to 128 wavelengths with no interruption in service, therefore all dispersion compensation and amplifiers are installed into the system to allow the full upgrade to take place over the time specified within the tender.

2.1 Network Elements in Optosunet

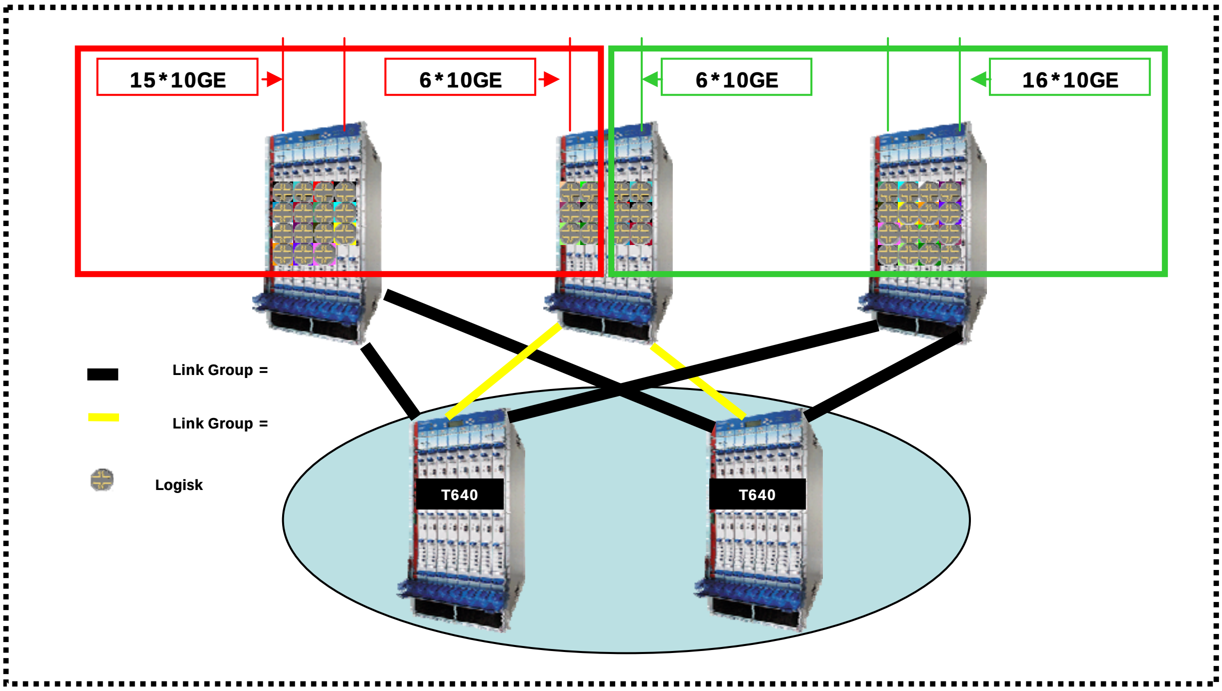
Centralized Layer 3 functionality with the option of Logical Routers

In Stockholm, all Layer 3 functionality resides in the constellation of five Juniper T640 routers and is designed in a way so that each Type A university can make use of Logical Routers.

The Juniper T640 can handle up to 16 logical routers as of 2008, and SUNET is able to provide Logical routers for all Type A customers spread over the three access T640´s. A Logical Router represents a customer router within the central routing solution. When the network administrator of a customer logs in to the Logical Router the users privileges are tied to this logical router. Also the routing functionality is separated from all other routing processes in the system. Configuration of routing protocols, policies and access-lists are done by the University administrators themselves through logical router admin control within the T640.

In essence, Type A customers can use the logical router as their primary router instead of having this function at the University. All Universities which have chosen this approach can decide which interior routing protocol to use (IS-IS or OSPF) between customer owned CPE routers at the University and the Logical router itself. As EGP (Exterior routing protocol) iBGP is used.

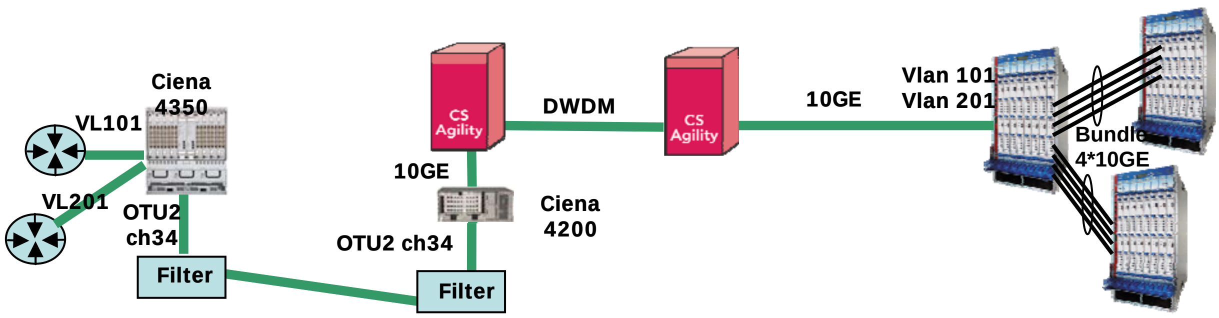
Failure on a link or any other primary router failure (physical or logical) will result in a switchover to the other connection. The time to converge between primary and secondary access is dependent on the IGP chosen (OSPF or IS-IS) together with iBGP, and how optimized the configuration is e.g. timers, use of BFD etc. The initial baseline tests indicate a sub minute convergence time.



The above picture shows the access (upper three routers) and core (lower two routers) layer of the central router design. All 10GE customers have redundant connections to two of the three top Juniper T640 routers. Between access and core the T640´s are connected with an Ethernet link aggregation (LaG) bundle of up to 4*10GE.

All Type B 1GE customers have redundant connections to the two core T640 routers.

At the premises of the type A customers, the Ciena 4350 Layer2 Ethernet switch provides customers with access ports. The customers can choose between 1GE and/or 10GE. All used ports will end up in the central T640 as a tagged VLAN (VLAN 101-109 for 1GE and VLAN 201 for 10GE)



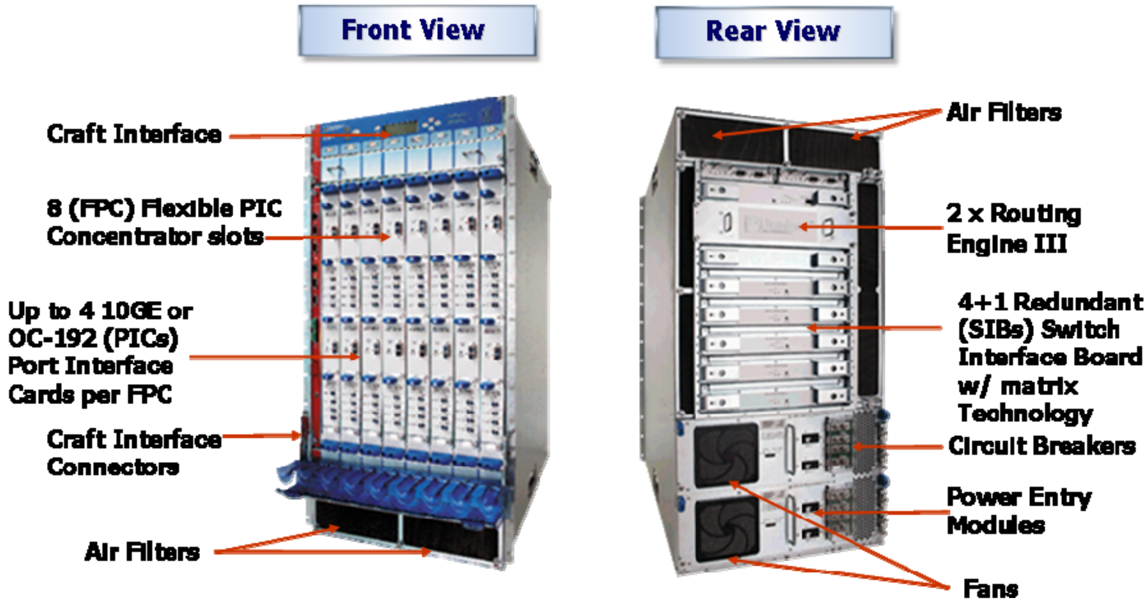
Customer VLAN´s

When all connections are partitioned with VLAN´s it is very easy to provide logical connections to customers and external parties centrally, in and outbound from Stockholm.

2.2 *Juniper Networks T640 Router*

The Juniper T640 Router delivers Gigabit Ethernet, 10-Gigabit Ethernet, OC-48/STM-16 and OC-192/STM-64 interfaces in a multichassis-capable system, and also supports OC-768C/STM-256 interfaces (40 Gbps). The T-series routers use JUNOS software and Juniper Networks-developed custom ASICs.

Figure: T640 Internet Routing Node – Chassis Front-Rear



2.2.1 T640 Architecture

Design Objectives

The T640 was developed to support seven key design objectives:

- Packet forwarding performance
- Bandwidth density
- IP service delivery
- Multichassis capability
- High availability
- Single software image
- Security

2.2.2 JUNOS Internet Software Architecture

The JUNOS Operating System is based on a design that Juniper Networks wrote from scratch to provide the stability, performance, and scale required for an Internet router.

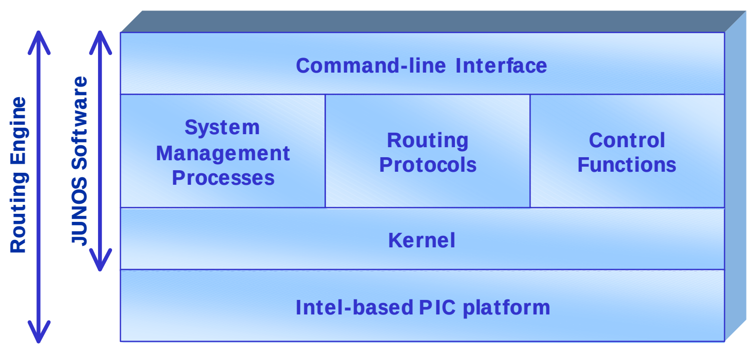


Figure: Routing Engine and JUNOS Software Architecture

The software consists of a series of system processes that handle the router's management processes, routing protocols, and control functions. The JUNOS kernel, which is responsible for scheduling and device control, underlies and supports these processes. The JUNOS architecture is a multi-module design, with each process running in protected memory to guard against system crashes and to ensure runaway applications do not corrupt each other. This modular design makes it significantly easier to restart or upgrade a specific module since you do not have to reboot the entire chassis. Between these independent modules, there are clean, well-defined interfaces that provide interprocess communication, resulting in highly reliable software architecture.

JUNOS software resides in the Routing Engine. The Routing Engine connects directly to the Packet Forwarding Engine. This separation of routing and forwarding performance ensures that the Routing Engine never processes transit packets. Of the traffic that goes to the Routing Engine, link-level keepalives and routing protocol updates receive the highest priority to ensure that adjacencies never go down regardless of the load, thereby preventing failures from cascading through the network.

Additionally, the JUNOS software passes incremental changes in the forwarding tree to the Packet Forwarding Engine so that high rates of change are quickly and cleanly handled. Together, the nearly instantaneous routing updates and the JUNOS software ensure that the Packet Forwarding Engine continues to forward packets at wire rate during times of heavy route fluctuations.

2.2.3 Juniper Networks support of Logical Routers

Logical routers provide the flexibility that network operators require to consolidate and tune the operation of their networks to accommodate different services without deploying additional physical routers. Logical routers allow partitioning of a single physical router into multiple logical routers, where each logical router performs independent routing tasks. This lets operators manage their CAPEX by consolidating the network hierarchy onto a single highly available router. Additionally, logical routers can reduce OPEX by supporting better asset allocation, streamlining growth management at the edges of the network, and reducing the complexity of the physical network topology.

Logical routers also support a variety of new services such as the ones deployed in OptoSunet's network, where each Logical router corresponds to a customers-premises equipment (CPE), managed by the customer. Finally, Logical routers can be used as proof of concept services deployments, with non disruptive testing.

Juniper Networks supports the concept of logical routers on the M-series and T-series platforms.

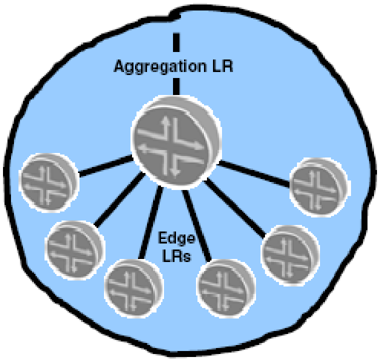


Figure: Collapsed Network Topology Using Logical Routers

A logical router is a partition of a physical router's resources that can contain multiple routing instances and multiple routing tables. A set of logical routers within a single physical router can support the functionality previously performed by several smaller routers.

Logical Router Design Considerations

One of the most important considerations when vendors architect a logical router implementation is ensuring a satisfactory balance between logical router isolation and network design flexibility. Logical router isolation is important because it enhances the security and availability of each logical router; while network design flexibility enables cost-effective deployments and provides the agility to solve a variety of real-world networking problems.
One design approach is to bind all of the interfaces on a given line card to dedicated routing engine hardware that executes a single logical router. This architecture delivers complete logical router isolation but provides limited configuration flexibility. The consequences of this approach are that each logical router requires a dedicated physical uplink since it cannot share logical interfaces of a given physical uplink with other logical routers, the unused physical interfaces on a line card cannot be assigned to another logical router, and the requirement of dedicated physical interfaces and routing engine hardware for each logical router creates an expensive solution.

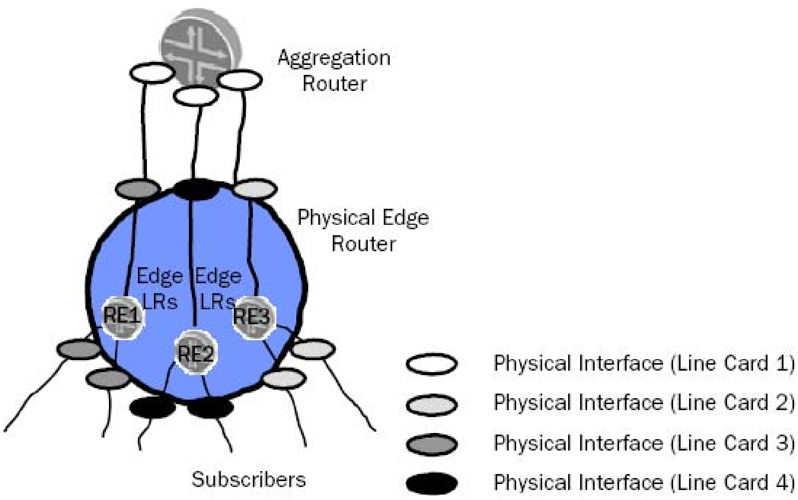


Figure: Logical Routers with Line Card Interface Granularity

Another approach is to bind individual physical or logical interfaces to a logical router instance that executes on a common routing engine that executes all logical routers. This architecture delivers partial logical router isolation but provides unlimited configuration flexibility because it allows any physical or logical interface in the chassis to be assigned to a logical router. The consequences of this approach are that each logical router, using logical interfaces, can share a physical uplink with other logical routers, any physical or logical interface in the chassis can be assigned to a logical router, and the use of shared uplinks with common routing engine hardware provides a cost-effective solution. This is the solution chosen by Juniper Networks.

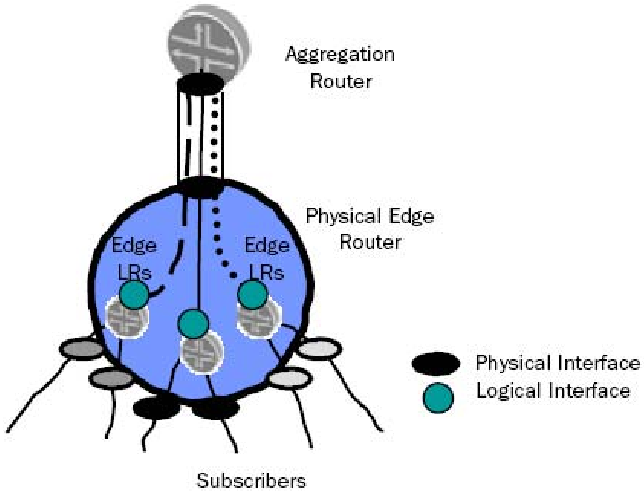


Figure: Logical Router with Logical Interface Granularity

JUNOS Software Features and Capabilities for Logical Routers

- A maximum of 16 logical routers can be configured on a single physical router.
- Physical and logical interfaces can be assigned to a logical router. After a physical or logical interface is assigned to a logical router, it is considered part of that logical router and cannot be assigned to another logical router.
- All physical interface properties (such as encapsulation types and interface related options) are configured on the physical router's main router.
- The Tunnel Services PIC supports the configuration of logical tunnel interfaces that provide point-to-point connectivity between different logical routers configured within the same physical router. This allows inter-logical router connectivity instead of wasting expensive physical interfaces on the front of the chassis.
- Unicast routing protocols such as OSPF, ISIS and BGP are supported by each logical router.
- Multicast protocols, such as PIM and DVMRP are supported by each logical router, including Rendezvous point (RP) and source designated router (DR) functionality.
- For each logical router, the routing information base (RIB) is maintained separately from the forwarding information base (FIB). The RIB contains all of the routing information that is received from the logical router's peers, including information learned from all routing protocols. The JUNOS software installs active routes from the RIB into the FIB. The FIB is the table that the logical router uses to forward IP datagrams. At a minimum, the FIB contains the network interface identifier and the next hop information for each reachable destination network prefix.
- Logical routers are separate from a policy perspective – each logical router can be configured with its own firewall filter policies and routing policies. Firewall filter policies control which packets are allowed to transit each logical router's interfaces to destination networks and which packets are sent and received by the logical router's control plane. Routing policy controls the import and export of

routes between the routing protocols and the routing tables, and between the routing tables and the forwarding table for each logical router.

2.3 Ciena Corestream Regional (CSR)

Ciena CoreStream Regional consists of a number of components that are used to drop DWDM channels at each Point Of Presence (PoP) site in the University cities.

Terminal

The fiber direction decides if a terminal is conceptually West or East facing. In Stockholm all terminals are east facing (by definition). All the terminals in the end of the spans are therefore west facing.

The terminal provides transponder functionality where an interface is connected to other components (CN4200, CN4350 etc.); the interface could be STM, Ethernet or OTU-2 in this design.

C-OADM with 8-channel add/drop capability

A C-OADM node is a network element that enables from zero to eight wavelength adds/drops per span direction, without requiring the pass-through (express) wavelengths to be electrically regenerated.

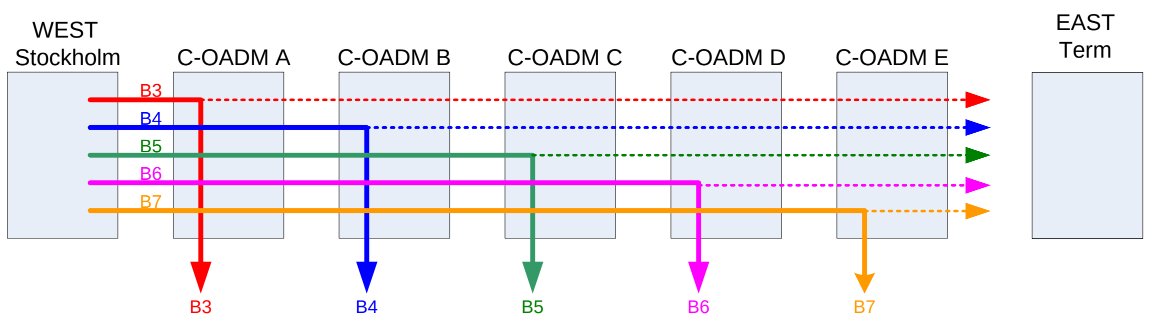
A fully-populated C-OADM node requires one regional shelf and one channel shelf. Unlike other OADMs, the dropped wavelengths may not be reused locally. Due to the optical architecture of the C-OADM, the fiber spans following a C-OADM without any Raman cannot exceed 22 dB span loss.

The C-OADM node supports 10G G.709 transceivers and 10G G.709 muxponders (MUXCVRs). A 2.5G add/drop capability is provided to the C-OADM through the client interfaces of the 10G G.709 MUXCVRs. The channel shelf on the C-OADM is configured with the Mux/Demux-50 circuit packs.

COADM Solution - Design Concepts

• Stockholm as an origin with bi-directional broadcast design.
• One band (8 channels) per COADM – add/drop kit in West (Stockholm) Facing Direction.
• “Pseudo-Drop and Continue” band concept – 8 channels in the same band can be split between multiple nodes as long as there is no channel duplication.
• Only one band can be added/dropped in each COADM.

Figure: COADM Drop (and continue)

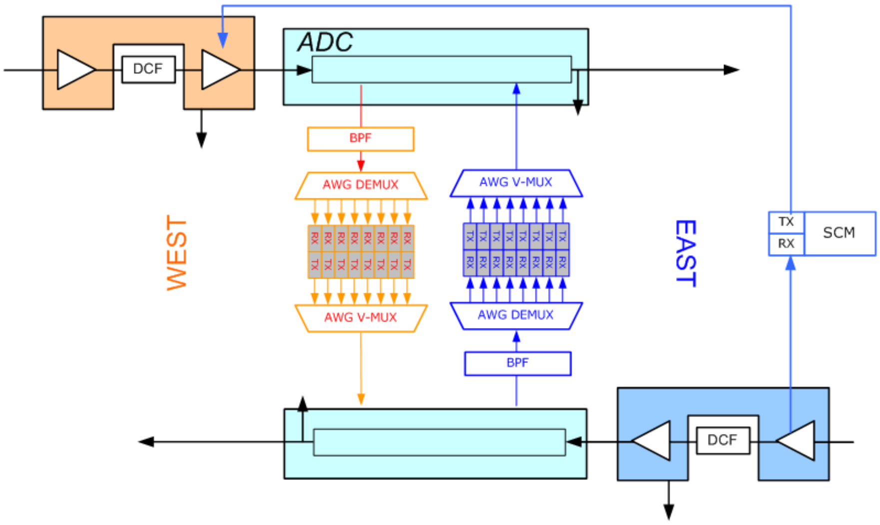


Functional Block Diagram

• Dual ADC support both East-Facing and West-Facing in direction.

• 2 Band Pass Filters (BPFs) to support both directions.

Figure: ***Block Diagram Concepts***



Limitations

• New COADM might not have pt-pt connectivity unless there are open bands.

• Span with 5 COADMs allows for only 9 out of 15 pt-pt links.

GD-SOADM with full C-band add/drop capability

The reason for using GD-SOADM in the network is for the regeneration of optical signals when they have become degraded, and not only for amplification due to OSNR values being to low.

The GD-SOADM is an extension of the Core Stream Regional Solution, enhanced to provide a reconfigurable optical channel add/drop network element with directional node isolated redundancy. This directional node redundancy allows the East or West facing add/drop channels to continue to operate normally in the event that the common elements in either the East or West section of the node fails.

GD-SOADM provides a reconfigurable OADM with geo-diverse redundancy. The GD-SOADM nodes are always deployed as a complementary pair, identified as GD West and GD East. A maximum of eight GD-SOADM pairs are allowed per span. Each GD-SOADM pair carries an OSNR penalty of a 25 dB segment.

Characteristics

The GD-SOADM supports:

- 2 degrees of express connectivity (East & West).
- 1 degree of add/drop connectivity (East or West).

There are two PoPs in the network populated with this solution. We have used the GD-SOADM at the Karlstad PoP in the Red West network span between Stockholm and Göteborg, and also at the Sundsvall PoP in the North Red span between Stockholm and Luleå.

OLA (Optical Line Amplifier)

OLA´s are placed along the spans where amplification is needed due to fiber attenuation. Each OLA in a span performs the following:

- Re-amplifies signals originating from Terminal or OLA nodes for continued transmission through the span.
- The OLA Intercepts and de-multiplexes supervisory channel data.

The amplifier sections of the terminals (transmit and receive amplifiers) and Optical Line Amplifiers use common components like ILA2 also used in CoreStream Terminals, COADM and GD-SOADM.

RAMAN Amplifiers

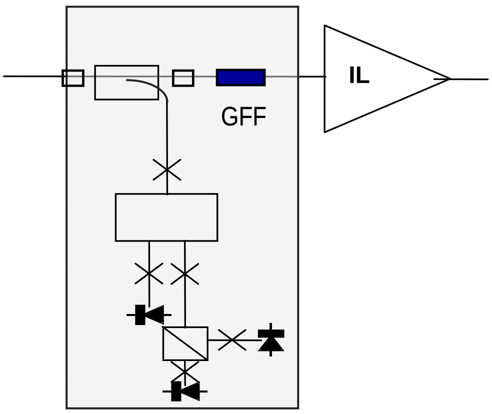
Raman amplifiers are used in the network on several different spans and the reason for their use is when fiber attenuation in the span is too high. Raman amplifiers provide an additional 8 to 10db gain for high loss spans for NDSF/NZDSF fibers. It minimizes non-linear effects and improves the OSNR characteristics of the fiber.

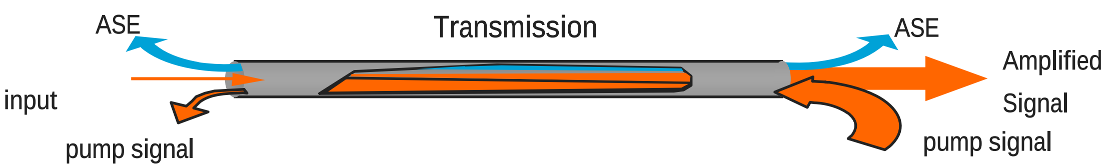
Raman is used in the following sites:

E=Eastbound, W=Westbound

- North Green: *No use of Raman amplifier*
- North Red: *No use of Raman amplifier*
- West Green: *No use of Raman amplifier*
- West Red: Västerås W, Västerås E, Örebro W, Örebro E, Karlstad W, Trollhättan E, Göteborg W
- South Green: *No use of Raman amplifier*
- South Red: Klevshult W, Klevshult E, Kalmar E, Kristianstad W

Figure: ***Raman logics***





2.4 *Optical Bypass Application in the Stockholm Central Node*

Introduction:

The scope of this chapter is to detail and summarize the application of the Optical Bypass feature of CoreStream Systems specifically applied in the Central Node in Stockholm.

Optical Bypass (OPB) Definition:

The Optical Bypass (OPB) application allows individual wavelengths to be expressed to the next node without the need for regenerators. The Mux/Demux-50 demux output at one node is directly connected to the Mux/Demux-50 mux input in the next node. This eliminates the need for back-to-back channel cards at the node. OPB is applicable only for Terminal and GD-SOADM nodes.

Optical Bypass Purpose in OptoSunet Network:

The main purpose of OPB in Stockholm is to allow for the creation of point-to-point connections between different PoPs throughout Stockholm without regeneration of signals as they switch between one section of the network and another. This simplifies the connection procedures as well as saving capital expenditures due to the fact that regeneration transponders are not needed in Stockholm.

Optical Bypass Requirements:

To be able to execute OPB in Stockholm, terminals need to satisfy the following hardware criteria:

- The Regional Shelf requires the Router-10B circuit pack.
- Optical Bypass channel shelves require the USA-3T shelf amplifier.

Optical Bypass Restrictions:

Optical Bypass cannot be applied for all desired point-to-point connections. There are two design limitations that define when OPB can or can not be applied:

1. Lambda Frequency Matching Limitations.
2. Optical Performance Limitations (OPB Circle around Stockholm).

1. Lambda Frequency Matching Limitations

To be able to apply OPB for a lambda between two CoreStream links, the frequency of the channel on one link needs to match the frequency of the channel on the other link. Basically, the channels that are candidates for OPB need to be of the same frequency on their respective links.

In the current design where most of the PoPs are COADMs, each COADM adds/drops a specific band to/from Stockholm. This means that if we want to create the OPB for the point-to-point connection between two PoPs we can create OPB only for PoPs that drop the same bands on their respective CoreStream links as their channel frequencies will be able to match. This limits the number of OPB connections that can be created for different point-to-point connections. For example, the band allocations in Green North and Green West links are as follows:

Green North	Band Number		Green West	Band Number
Uppsala	**3**		**Västerås**	**3**

Gävle	**4**		**Örebro**	**4**
Sundsvall	**5**		**Skövde**	**5**
Umeå	**6**		**Borås**	**6**

If we would like to create a point-to-point connection between Uppsala and Västerås the OPB would theoretically be possible as they add/drop the same bands, but if we would like to create a point-to-point connection between Uppsala and Skövde this would not be possible as they add/drop different bands. To change this current design, this would require changes to the band allocations for each COADM involved, or upgrade of COADM to GD-SOADM as GD-SOADM allows for any channel to be added or dropped. It is important to notice that this band limitation does not apply to Terminal and GD-SOADM PoPs as these nodes allow for any channel to be added or dropped, so from these nodes channels of any frequency can reach Stockholm.

2. Optical Performance Limitations (OPB Circle)

After the above mentioned channel frequency rules are applied, it does not mean that for any point-to-point connection we can use OPB. Even if the channel frequencies match, some channels are optically limited as to how far they can go without regeneration, and for those we would not be able to apply OPB in Stockholm. The simplest example is the point-to-point connection from Luleå to Göteborg. Even though these are Terminal PoPs and don't have any channel frequency limitations, they are on the opposite sides of their respective links and it is optically impossible to create OPBs for channels that are coming from these PoPs.
Keeping this optical performance limitation in mind, we can define certain PoPs that are close enough to Stockholm so that we can create OPBs for their channels within the optical performance specs. After review, the following PoPs are within allowable optical range of Stockholm and we can create OPBs for channels that originate at the following PoPs:

- Uppsala (Green or Red North)
- Gävle (Green or Red North)
- Västerås (Green or Red West)
- Örebro (Green or Red West)
- Linköping (Green or Red South)

These PoPs create what can be referred to as an "OPB circle" around Stockholm, as we can use OPBs for any point-to-point connection between these PoPs, keeping in mind the frequency rules. It is important to notice that the list above does not mean that OPB will not work for any other PoP point-to-point connection. There is a possibility that the OPB circle can stretch more in one direction than another. For example more North towards Sundsvall Red PoP but less West towards Västerås Green, and that OPB works for this point-to-point connection.

2.5 Ciena CN4200

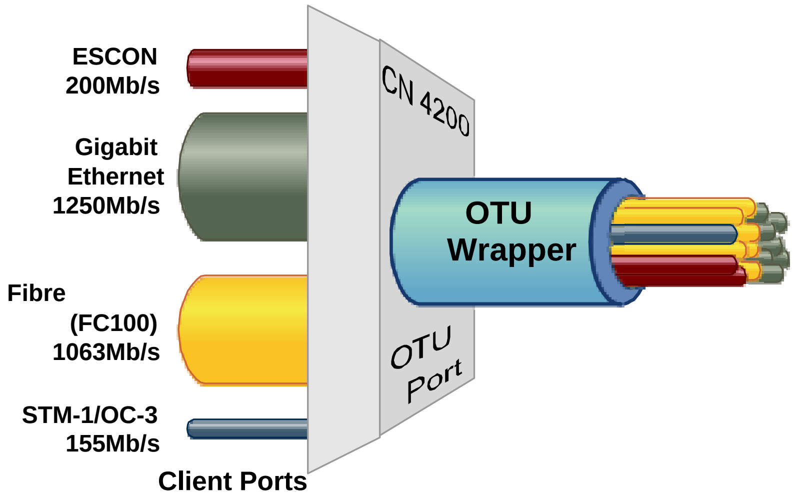
In the OptoSunet solution we use the CN4200 chassis which is 4RU high with 5 slots that can hold 4 interface cards and 2 filters. We use ITU G.709 standards-based technology (also known as OTU Digital Wrapper) to groom multiple optical services that can run on any port on to OTU2 (10.7 Gb/s) wavelengths. Standards-based protocols supported include: 10/100/1000 Ethernet, 10GbE LAN/WAN, OC-3/12/48/192 or STM-1/4/16/64, FC, ESCON, OTU1 and OTU2.

The CN4200 is used for terminating 1GE connections for Type B customers and also for LDGEs (Low Density Gigabit Ethernet) and for 10G OTU-2/10GE connections.

We use 3 different types of interface cards with the CN4200. M6 (two different versions) and F10-A modules provide client interfaces for Type B customers and LDGE, as well as aggregating and transporting lower speed services over OTU2 wavelengths. F-10T modules provide 10GE connectivity over OTU2 wavelengths. Each span of CN4200 can support up to 40 express or local wavelengths. At the Green or red PoPs where we use the CN4200 as an aggregator of LDGEs the CN4200 chassis is located in the same rack as the CoreStream COADMs.

For a few spans we use the CN4200 as a transport platform to extend certain CoreStream spans. In these cases we're also using amplification modules where needed. These spans are limited to: North red (Tuggen to Umeå), South green (Malmö to Halmstad) West green (Örebro to Karlstad) and the "Blue" network as an extension of North green from Luleå to Kiruna.

Figure: ***Principle for OTU-Wrapper***



2.6 Ciena CN4350

The CN4350 system is a ten slot switch chassis with redundant common equipment.

Major CN 4350 components include the 160 Gb/s Fabric and Control module (PFX-80), 10 port 1 Gigabit Ethernet Module (PSC1), and 1 port 10 Gigabit Ethernet Module (PSN10). The PFX80 provides non-blocking connectivity between all 8 interface module slots. Each interface slot can be populated with any mix of PSC1 and PSN10 modules, supporting up to 80 full duplex Gigabit Ethernet or eight 10 Gigabit Ethernet ports. The PSC1 and PSN10 support pluggable optics, SONET-like performance monitoring, packet processing and embedded signalling and control channels.

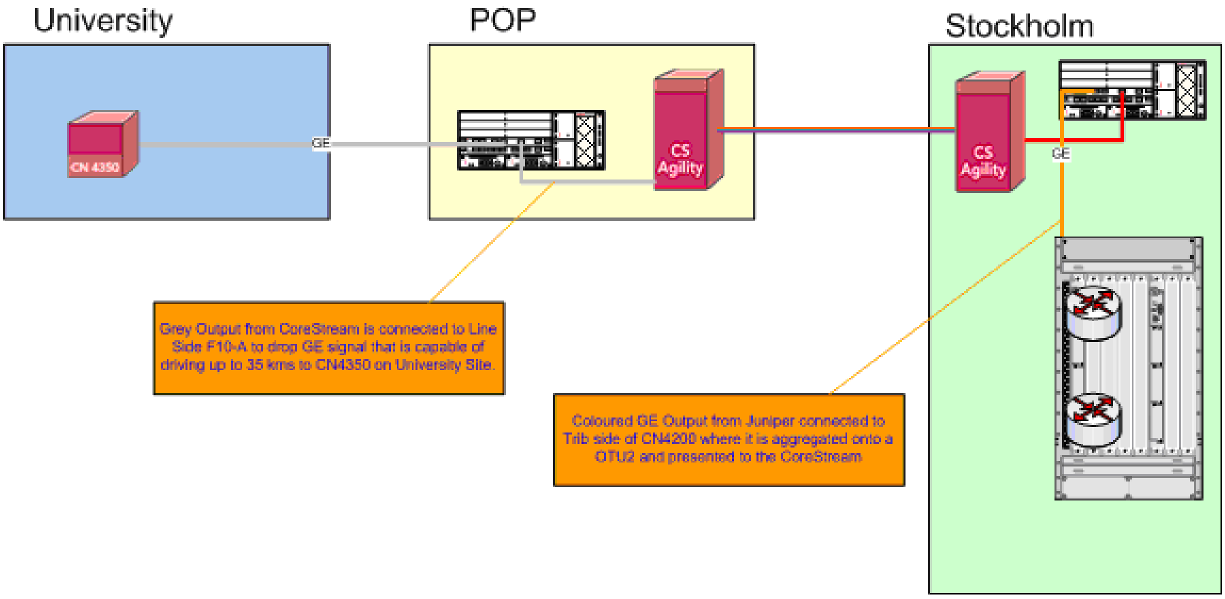
In OptoSunet each CN4350 is equipped with a PSC-1 module in Slot 1, PSN-10 Ch37 in Slot 2 and PSN-10 Ch34 in Slot 8. The PSC-1 interface card is used as the 10-to-1 converter for the type A type customers, who don't have 10GE capable equipment yet. Actually, the university can use 9 ports since one port is used to connect the DCN management network between Green and Red networks.

3 OptoSunet connections

3.1 1 Gigabit Ethernet Connections (GE)

The Ciena CN4200 is used for LDGE and type B customer connections. All 1GE´s are transported within an OTU-2 framed DWDM channel (10.7G) which is terminated in a CN4200 at the central site in Stockholm where the 1GE is “handed over” to one of the two core T640’s.

3.1.1 Customer Type B

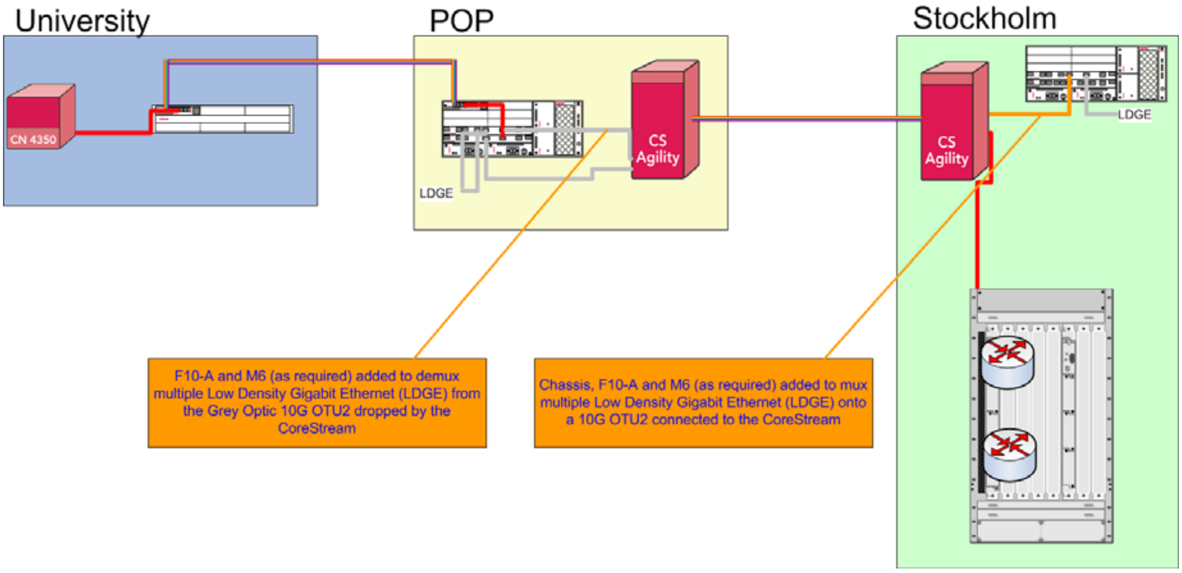


1) At Stockholm an F10-A (and M6 card if required) is used to aggregate the GE onto an OTU2 which is fed to the Core Stream.

2) At the PoP the Grey output from the Core Stream is fed to the Tuneable line port of an F10-A and GE is then dropped for transport to the University. There is no requirement for the ability to add additional connections to the University as only type A customer sites will require point-to-point connectivity.

3.2 LDGE´s for other connections

SUNET has a requirement to drop up to 6 Low Density Gigabit Ethernet connections (LDGEs) from different PoPs back to Stockholm.



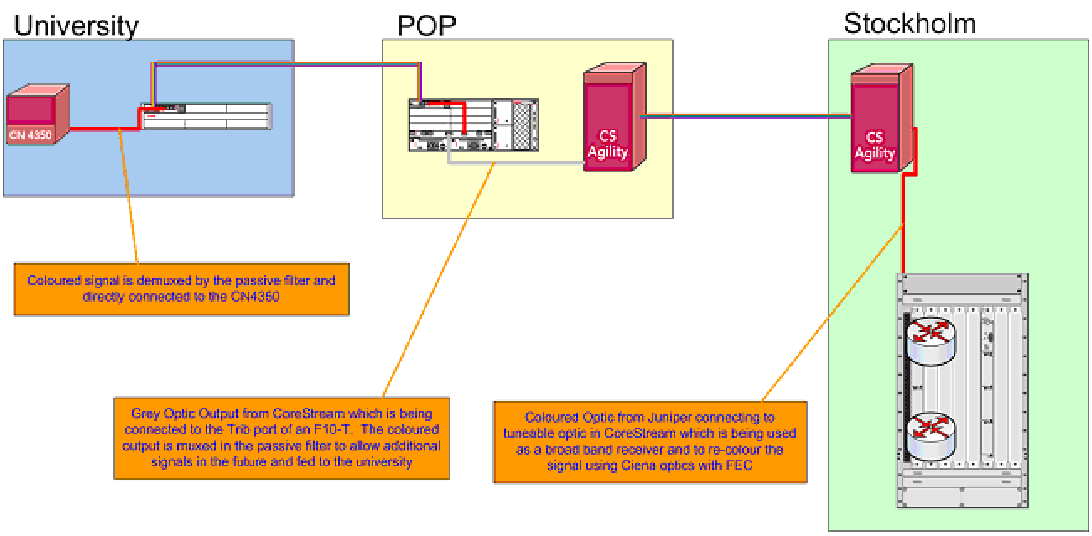
1) To accomplish this F10-A's are required at Stockholm and the PoP (potentially with M6 cards to act as a controller) to aggregate the LDGEs onto an OTU2 signal as illustrated above.

3.3 10 Gigabit Ethernet Connections (10GE)

3.3.1 Customer Type A

All Type A Universities have 10GE options. 10GE is transported from customer premises over an OTU-2 uplink from Ciena 4350 (CPE) to the PoP. In order to match the central Juniper 10GE interface the OTU-2 goes into a 10GE on the PoP 4200 and then into the Core stream regional DWDM system for transport to central Juniper T640 routers in Stockholm.

For Type A customers the connection between the PoP and University site consists of a 4 channel filter (ch34-ch37) which enables 4 different wavelengths. Only Channel 34 is currently used for the 10G OTU-2 Uplink.



1) The proposed solution takes a tuneable output from the Juniper device directly into the Core Stream where it is 're-coloured' using Ciena optics (including FEC for the Long Haul capability) and muxed onto the fibre for transmission to the PoP.

2) At the PoP the Core Stream drops the 10GE as a grey Optic signal, this is connected to the trib port of an F10-T where it is coloured by a Ciena tuneable optic and muxed via a passive 4 channel filter to be transmitted to the University.

3) At the University the signal is extracted from the 4 channel filter and directly connected to the coloured optic of the CN4350.

STM-16

The customers in Visby and Kiruna use the leased STM-16 for access. In Kiruna, the STM-16 is used for redundancy and is rented from an external provider. This leased STM-16 terminates in Luleå where it is transported over the Red CoreStream network for termination in one of the central Juniper routers.

STM-64

An STM-64 is transported in the Blue network in a DWDM channel between the local 4200 in Kiruna and is terminated in the Luleå Blue 4200.

OC-192

OptoSunet provides OC-192 access to the SP Technical Research Institute of Sweden. This OC-192 is transported from Borås to the central Juniper router in Stockholm.

3.4 Point-to-point connections

All “customer type A” sites can easily be upgraded to accomplish point-to-point (p2p) connections. The basic design allows easy setup of such connections to the central node in Stockholm, but it is also possible to rebuild the nodes to allow such connections between other city pairs (but not every city to every other city) e.g. the 1GE from Luleå University (LTU) to Umeå University (UmU). This connection is transported from a standalone 4200 at LTU to a standalone 4200 at UmU. It is transported in the Green network in an OTU-2.

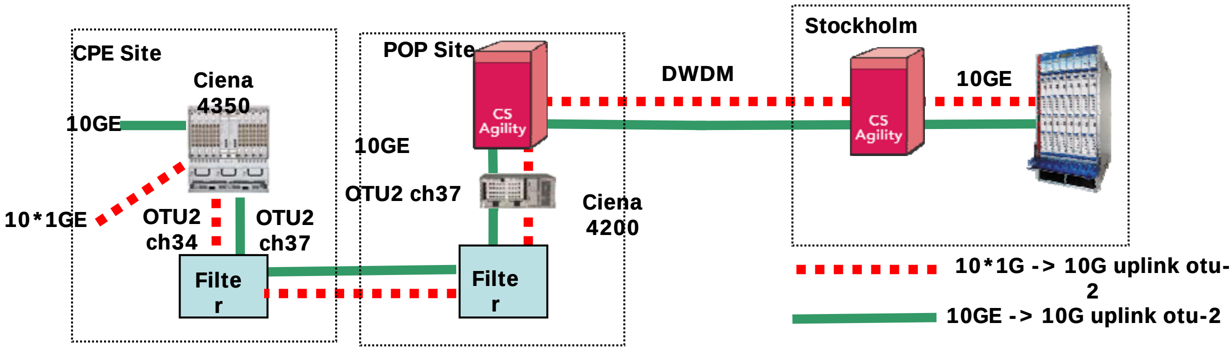
4 Examples of new connections in Optosunet

Example 1 – Adding 10G capacity University – Stockholm

The following example describes a possibility for Type A Universities to add 10G (i.e. 10GE or STM-64) capacity over the OptoSunet DWDM backbone to be terminated in Stockholm. The connection in Stockholm could either be terminating in an existing T640 router or another destination of the customer's choice.

Additional capacity is already in place at the customer's premises with the 4 channel filter installed at every Type A site. In addition each 4350 is equipped with a 10GE/OTU-2 interface card using Channel 37 installed in slot 2. This card is used for 10GE customer access. But as an example, lets use this card as an uplink 10GE->OTU-2, meaning the customer will get 1*10GE + 10*1GE (over a 10G uplink). This is possible by setting the interface to Transponder mode.

Figure: Dual 10G uplinks from a Type A university

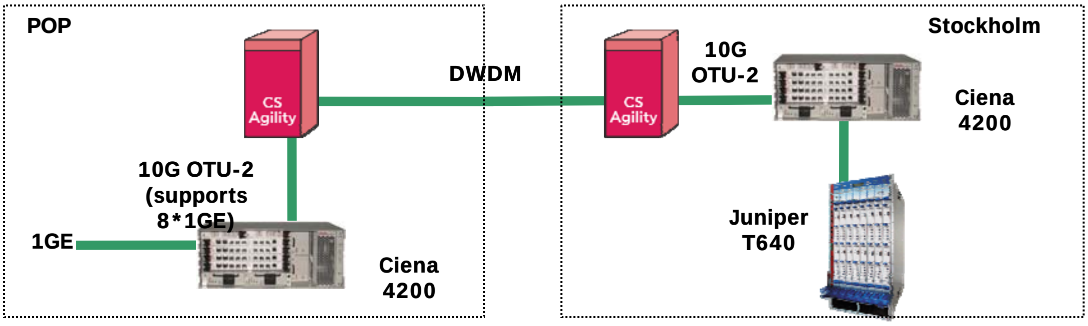


Connection inventory

CPE 4350 User PSN-10 Slot2	CPE 4350 Network PSN-10 Slot2	CPE CN100 filter	POP CN100 Filter	POP 4200 F10-T OTU-2	POP 4200 F10-T 10GE	POP Core stream Transceiver 10GE	Sthlm Core stream Transceiver 10GE	Sthlm Access 10GE Terminated
10GE LanPHY Gray	**OTU-2 Channel 37**	**Channel 37**	**Channel 37**	**Channel 37**	**Gray Optics**	**Gray Optics**	**Gray Optics**	**Gray Optics**

Example 2 – Adding a LDGE from a PoP site – Stockholm

OptoSunet supports adding 1GE connections from PoP sites in each city. LDGEs are transported over OTU-2 from the PoP to the central site in Stockholm. An OTU-2 can transport up to 8 GE in a single 10G channel.



Connection inventory

POP Site 4200 F10-A	POP Site 4200 F10-A	POP Site Corestream Tranciever	Sthlm Corestream Tranciever	Sthlm 4200 F10-A	Sthlm Access 1GE Terminated
1GE (LDGE)	**OTU-2 Gray**	**OTU-2 Gray**	**OTU-2 Gray**	**Gray Optics**	**Gray Optics**

Note: *Customer Type B connection is achieved in exactly the same way as an LDGE connection.*