TECHNOLOGY PAPER ON
HIGH CAPACITY DWDM NETWORK

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COMMTEL

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1 Introduction

With the potential growth in new services such as Internet and E-commerce, telecommunications networks have to face new challenges. Optical WDM and now DWDM systems have established the path for a successful response to the continuos demand for services, requiring more capacity, requiring more bandwidth. The availability of flexible, modular DWDM systems will help the network operator building up of the network in stages. Optical add-drop multiplexer for the access network further supports this. The present growth in WDM component, sub-system and system technical development is a clear indication that the race for an all-optical network is wide open.

2 Scope

This document provides details on DWDM technology, optical fibers supporting the same and typical DWDM network. The scope of this document is limited to technical aspects only. The commercial details / budgetory costs will be provided later at appropriate time.

3 DWDM Technology

With the requirement of high bit data rate and availability of unlimited capacity of fiber, new technologies have evolved over the years. Traditionally, the transmission of optical signals was limited to two wavelengths such as 1310 nm and 1550 nm. However, with the availability of appropriate optical components, it is possible to transmit the signals using multiple wavelengths using only one fiber.

Wavelength Division Multiplexing technology provides an important and convenient method of increasing the information capacity of fiber optic data links and networks. The recent development of lasers that have reliable spacing of approximately 1 nm between adjacent channels and passive multiplexer and demultiplexers allows aggregate bit rates of many tens of thousand of Gb/s and potentially many hundreds of Gb/s capacity over a single fiber. This dense wavelength division multiplexing technology provides more rapid and scaleable method, compared to time division multiplexing for increasing the capacity of many types of fiber optic networks.

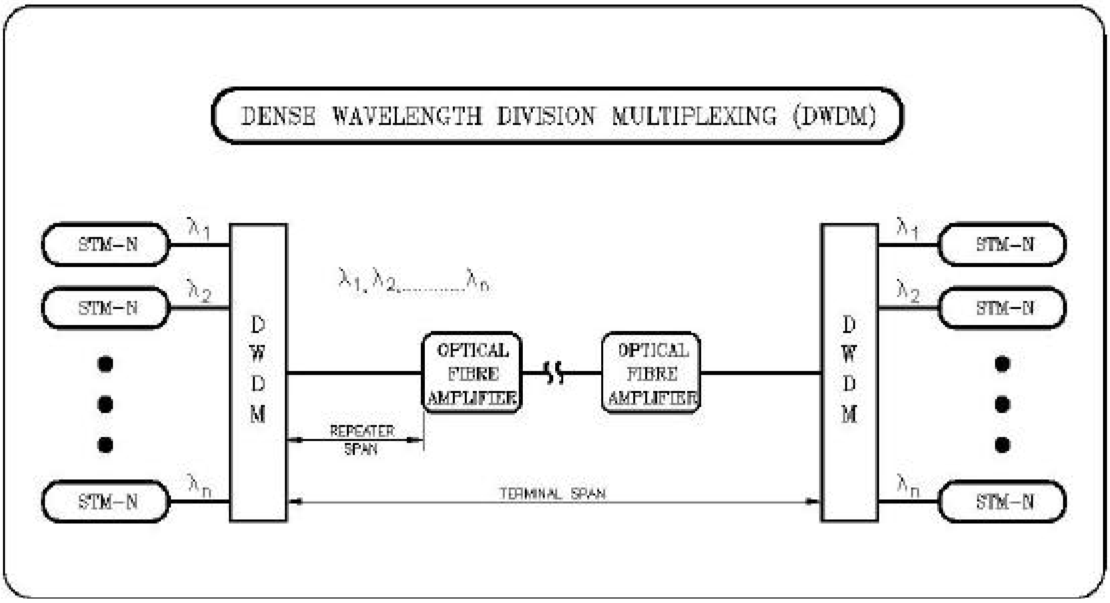
The use of dense wavelength division multiplexing provides simple yet powerful method of increasing channel capacity for digital multimedia systems. By using different lasers with systems that already have been designed for single wavelength the capacity can be increased in direct proportion to the number of lasers. There is no need to redesign the electronics for a higher bandwidth and existing components and modules can, to a large extent, be used in the higher capacity system. In addition, the use of lasers in the 1550 nm sprectal region allows DWDM to be combined with optical fibre amplifiers to extend the length of data link or more generally to be used with links with greater loss.

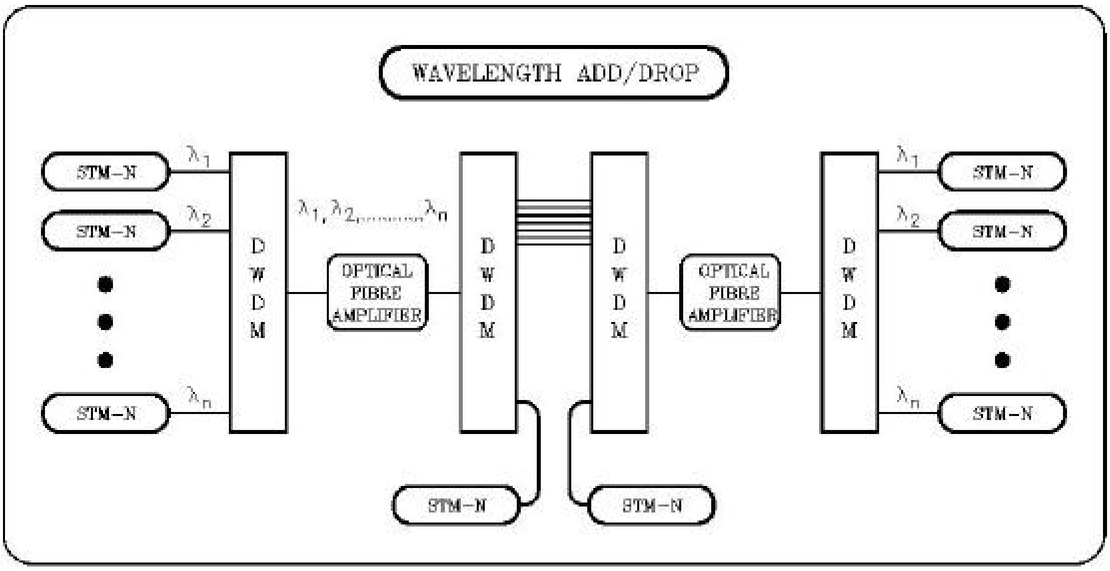
The evolution of Wavelength Division Multiplexing (WDM) started from using two different operating wavelengths such as 1310 nm and 1550 nm. With enabling technologies such as optical fiber amplifiers, DWDM boosts the network transmissions and provided more bandwidth. The Optical Fiber Amplifiers (OFA) provides simultaneous and direct optical amplification of many wavelengths. For example, with the sole use of TDM, 80 regenerators are required with 8 fiber pairs for optical transmission over 400 Km using, for instance conventional 2.5 Gb/s space division multiplexing with 80 Km between the regenerators. With DWDM and TDM together, only three amplifiers are required over the same 400 Km distance. This time, only one fiber pair is required to transmit for instance 2.5 Gb/s STM -16 with 80-120

Km between OFAs with 1,4,16 32/40, 64 or 80 wavelengths for metropolitan applications. OFA deployment helped reducing the space and power requirements and bringing the down the costs of construction.

Another technology that enables the increased use of DWDM is Optical Add-Drop Multiplexer (OADM). The OADM is specially suited to dropping traffic at smaller sites. Consequently, this opens up WDM transmission in the metropolitan areas where connectivity is a key issue as compared to long-haul transmissions where cost is managed per bit-kilometers is crucial. Current OADM technology supports 4 to 8 add/drop channels.

Following sketch shows the typical DWDM network.





From a technology point of view optical networking (routing) is still a few years ahead. That is why in large scale, all optical networking (routing only in optical domain) is not viable within the near future. Even then, it must provide better value than existing SDH based transport networks. This is based on three facts:

- All infrastructure changes are slow
- DWDM technology cost and sales prices must reduce significantly
- In access networks, and even in regional networks, smaller capacities (less than 155 Mbit/s) will be required for a very long time

4 Fibers Supporting DWDM

For transmitting the DWDM signal, the conventional single mode optical fibers i.e. ITU G 652 compliant, are not completely suitable. Due to availability of OFA working in 1550 nm region, the operating wavelengths are chosen in the C band i.e. from 1530 to 1565 nm. The ITU G 652 fiber has very high dispersion in 1550 nm region, which limits the distance between repeater station severely. With the help of linear imperical formula, it is possible to find out the maximum distance between the repeater station for a given bit rate and the dispersion. The formula is as follows:

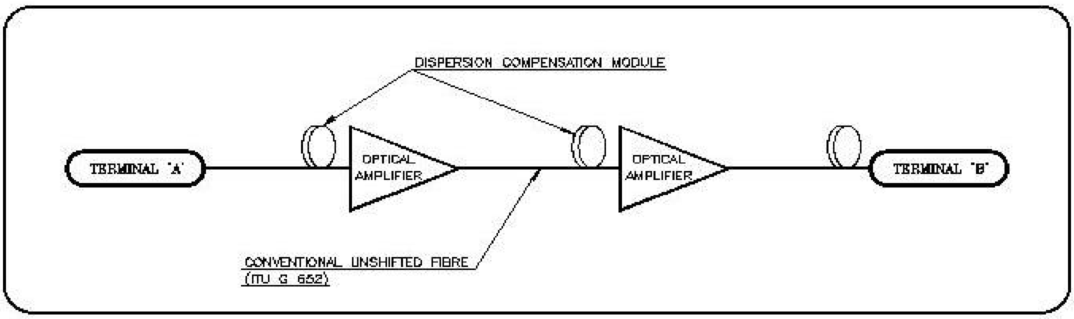
B^2 L D < 104,000 ………………………………… (1)

Where,

B= Bit Rate in Gb/s
L= Distance in Km
D= Dispersion in ps/nm-km

Please note that the above calculations are with 1 dB power penalty.

It can be seen that in case of ITU G 652 fiber with the high dispersion at 1550 nm, typically 18 ps/nm-km, the maximum repeater distance for a STM-16 (2.5 Gb/s) and STM-64 (10 Gb/s) system can be 800 and 50 Km respectively. Although, it is possible to compensate the dispersion by using dispersion compensating fibers (DCF), these DCF adds to additional optical loss. This requires the use of OFA, which can make up the loss due to DCF. Following sketch shows a typical network with DCF and OFA.



To summarise the need to compensate for high level of dispersion in ITU G 652 fibers adds four cost elements to the fiber network: (a) the cost of DCF module (b) the cost of extra amplification (c) OSP plant expenses associated with building and maintaining addition amplifications sites and (d) if more power amplifier are installed, additional costs required to re-engineer the DCF modules into the network. Furthermore, it is necessary to measure the actual dispersion of the fiber optic link instead of using theoretical values.

Conversely, in case of ITU G 653 fibers with zero dispersion at 1550 nm, the nonlinearities such as Four Wave Mixing (FWM) plays dominant role, rendering the fiber unsuitable for long distance transmission. A fiber that has small but non-zero amount of dispersion can minimise the non-linearity effects. The ITU G 655 compliant, Non Zero Dispersion Fibers (NZDF) has dispersion which is carefully chosen to be small enough to enable high speed transmission over long distances, but large enough to suppress FWM. With the proper use and placement of OFAs, it is possible to have the repeater less link. With the dispersion of 2.7 ps/nm-km typically in case of ITU G 655 fiber, it is possible to have repeater spacing of 1000 Km for 2.5 Gb/s systems and 200 Km for 10 Gb/s systems (refer to imperical formula 1 above). It shall be noted that the practical limit of most of commercial systems available is 20% to 40% lower than theoretical values. Moreover, the above figures represent the maximum distances after taking into account the dispersion only. A system designer needs to take into account power budget and link loss while deriving the repeater distances.

In summary, a future-proof fiber optic network should have combination of ITU G 652 and G 655 fibers. The number of each type of fiber in a cable is generally chosen based on the type of network. The complete fiber optic network can be defined in broader manner in two parts: (a) High capacity, long haul Backbone network or Transport network and (b) High Speed, Local Access network.

The Backbone network connects the major cities of the networks and carries high bit rate signals. In order to build economical and future-proof backbone network, sufficient number of G 655 fibers should be deployed in backbone network in addition to ITU G 652 fibers. In general, the average backbone network fiber count is 24. Keeping in view, the cost economics and network protection, the number of ITU G 655 fibers can be 8 and the number of ITU G 652 fibers can be 16.

The Local Access network is used for carrying the data up to the customer premises. Due to smaller spacing between the stations / customer premises equipment, the standard single mode fibers (ITU G 652) can be deployed. The number of fibers in the cable will largely depend upon the topography, topology and business plan.

5 DWDM Architectures

DWDM networks can be built using two different architectures viz. Stand-alone DWDM and Integrated DWDM. The stand-alone DWDM system is a good choice for increasing fiber capacity and reducing cost, but lacks many features like protection and path/traffic management. To achieve the benefits of both DWDM and modern SDH technology the best choice is to use an integrated application, which provides the support for high granularity data traffic (622Mb/2.5Gb).

Integrated SDH/DWDM applications can be seen as a working solution for datacentric transport. Whatever traffic scenario comes true, SDH VC-4 layer will be a cost effective and useful transport layer for different services. This comes from the fact that the difference between integrated and stand-alone (so-called "open") systems has largely disappeared. The differences are in the channel count, distance and bit rates. In transparency of stand-alone systems, which has the capability to transmit different signal formats, "openness" is often overstated, especially in long-distance networks.

The reality is that signals provided for transport networks have in most cases SDH framing

(VC-4, VC-4-4c, 620 Mbit/s and VC-4-16c, 2.5 Gbit/s) from new data devices. The SDH framing is excellent for carrying transport management information (i.e. performance and fault location data). Transparency is more important in metro networks where many different signal types exist and are for shorter distances.

The stand-alone DWDM system is a good choice for increasing fiber capacity and reducing cost, but lacks many features like protection and path/traffic management. **To achieve the benefits of both DWDM and modern SDH technology the best choice is to use an integrated application, which provides the support for high granularity data traffic (622Mb/2.5Gb**).

Initially, the proportion of high granularity data traffic is small, hence building stand-alone DWDM support just for that is expensive. Coupled with concatenation support, SYNFONET STM-16 SDH nodes, offered here, can carry both high granularity data and traditional traffic, thus providing a network wide service availability ranging from 2Mbit/s to 2.5Gbit/s. This service variety can be provided from all points of presence (POPs) in the STM-16 network. Transparency ("openness"), especially in long distance networks, is not as important because SDH framing in DWDM systems is required for performance monitoring and fault localisation. In addition, as mentioned above, the signal formats of data devices are increasingly SDH framed.

To summarize, the integrated SDH/DWDM system provides numerous benefits compared to stand-alone systems. These benefits are as follows.

- Standardisation
- Protection methods
- NW management channels
- Monitoring
- Synchronisation
- Grooming
- Common NMS
- Cost / coverage

… In addition, utilizes the benefits of DWDM!

6 NOKIA SYNFONET - SDH Integrated DWDM system

We have offered the SYNFONET, SDH integrated DWDM from Nokia which has been designed around a flexible transport network architecture, with the Open Topology approach. To make Open Topology a reality, the transport networks need to be flexible and able to grow and adapt according to the changing requirements over time. Nokia provides a set of scaleable network elements, which can change their roles in the network as the traffic grows.

Synfonet DWDM complements the Synfonet STM-16 transport product offering providing capacity of 40 Gbit/s (16*2.5 Gbit/s) in one fiber. Synfonet DWDM is a cost-effective DWDM solution for the STM-16 node, allowing DWDM to be used in applications where it was not previously possible. ***It makes DWDM competitive in short distance access and regional routes***.

Synfonet DWDM has been designed with the idea of having advanced, modular, readily adaptable network equipment. It enables operators to gradually increase transport capacities up to 40 Gbit/s while maintaining sophisticated network management and survivability.

The Synfonet DWDM solution is based on the field-proven platform of Synfonet STM-16. The wide variety of tributary units together with the support for concatenated payloads makes

Synfonet DWDM a powerful media for high-speed data signals. To build a high-capacity transport link, all you need is wavelength precise "multicolour" STM-16 interface units and wavelength division multiplexing and demultiplexing units (Figure 1).

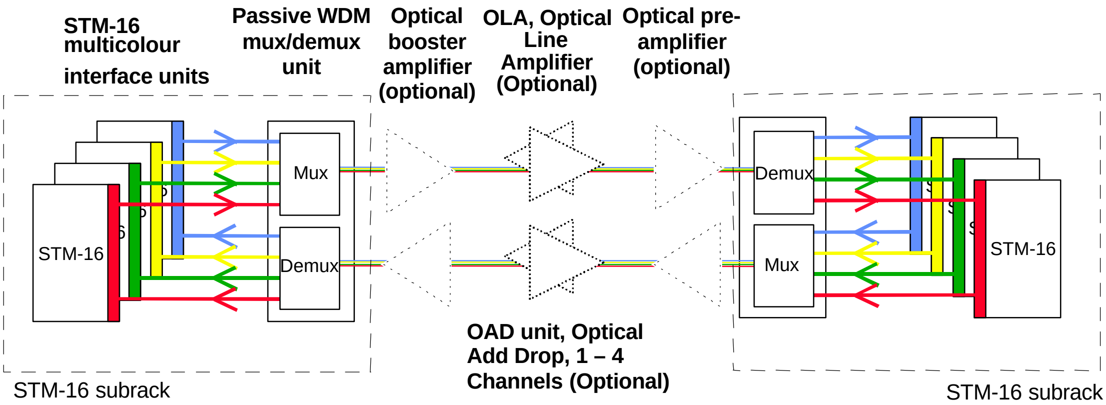


Figure 1. SYNFONET DWDM – basic system

SYNFONET DWDM is a very cost-effective, quick and easy way to increase capacity compared, for example, to adding fibre. It is intended for all applications for short to medium distances (10 – over 300 km) and capacities up to 16 channel (40 Gbit/s). Furthermore, it can be upgraded according to the need ("Build-as-you-go"), even start-up costs are minimal. For future-proofing of a link, only the multicolour interface card is initially required, and when a capacity upgrade is needed the additional channels and multiplexing units can be added.

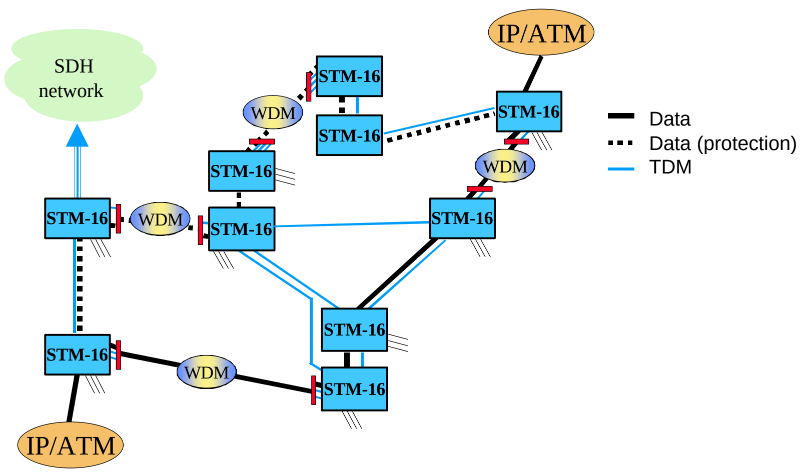


Figure 2. Example of SDH network with SYNFONET SDH and DWDM

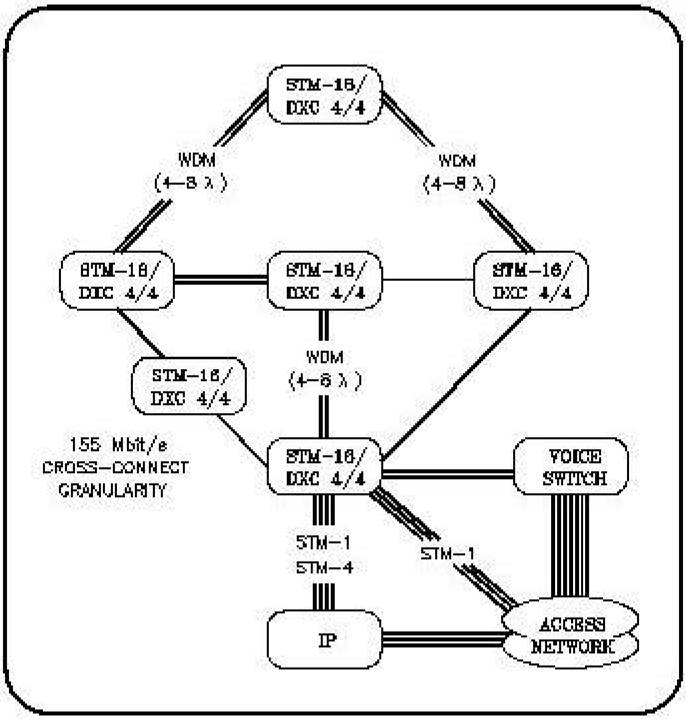
Because SYNFONET DWDM is part of the STM-16 node, only a few additional, relatively inexpensive components are needed. This, together with the simple, passive multiplexing technology creates a very robust and reliable system for large capacities.

The technology is based on well-known and proven SDH, which is familiar to operators. Because of this type of technology, the SYNFONET DWDM system does not need any additional network management. DWDM links will be displayed and documented in the Nokia NMS/100 network level management system.

7 Typical Network

With global trend towards privatisation of the telecommunications sector, gaining a competitive advantage in network design is critical. Those carriers that are successful must have low relative network expenditures, and the capability of expanding their system capacity in line with customer demand. With the availability of WDM/DWDM technology the cost of building the network with high data rate has come down substantially. As explained above in section 3 & 4, the perfect combination of technology and the supporting media will pay good dividends to network builder in the present scenario as well as in the future.

Following sketch shows the typical SDH over WDM network proposed for consideration. The actual network configuration depends upon the expected traffic by customer, locations, type of protection, etc.



With the heavy cost involvement in building up of the network, it is essential for an operator to choose a DWDM architectures, which gives flexibility of building up of network. We are outlining here an example of how an operator can build a modular, flexible, and expandable network.

In year 1 all the links are implemented with multicolour STM-16 interface units i.e. STM-16 interface unit with unique wavelength, that can be later upgraded with DWDM units. In year N, the traffic has grown and there is a need to upgrade the links. In the upper link DWDM mux/demux units are added to both ends of the link and one additional multicolour interface unit is added. In the lower link capacity need has grown so much that four colours are used - giving a total of 10 Gbit/s capacity in one fibre pair. Because the distance is further than in the upper link, in addition to the mux/demux units, optical booster amplifiers are also added.

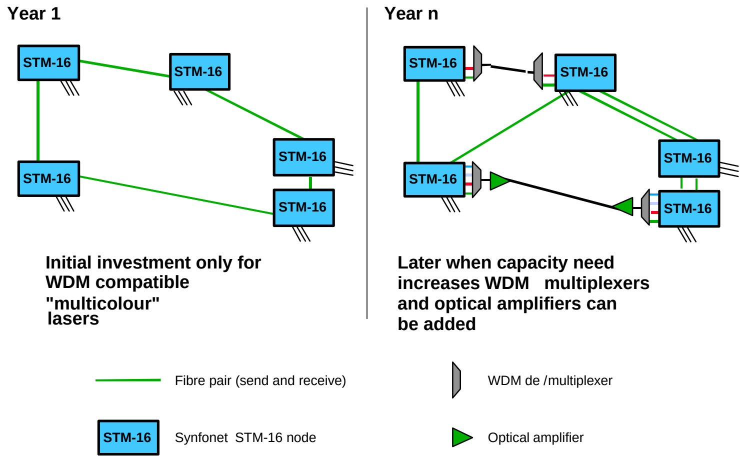


Figure 3. SYNFONET DWDM – Example of network growth

7.1 Limitations

While building of network, it is always necessary to understand the limitations or maximum capacity of the network. As outlined in the above section 3, the proper selection of optical medium i.e. optical fiber, is very crucial.

For those operators who intends to use the existing fiber optic network built with conventional single mode fibers (ITU G 652), the use of Dispersion Compensating Fiber module can be made. However, please note that each DCF module adds the optical loss to the tune of 5 dB and in order to make up the loss, optical fiber amplifiers (OFAs) are required.

Another, alternative is to deploy the ITU G 655 fibers on the backbone network as mentioned in the section 3.

8 Network Protection

With increased demand for high speed, high capacity, fault tolerant network, the proper selection of network protection is very crucial and important. Further, there must exist the facility to expand the network in future with the same network protection. The network protections can be provided at various levels, i.e. IP/ATM level, SDH level and WDM level.

An important feature of SDH network is the possibility of protection against network failures. This increases the availability significantly. SDH protection types are MS (Multiplex Section) trail protection and Path Protection. MS Trail protection can be divided into MS Trail Linear protection and MS Trail Ring Protection. Path Protection types are Sub-Network Connection Protection (SNCP) and Linear VC Trail Protection.

In case of MS trail protection, the working trail is replaced by a protecting trail if the working trail fails or its performance falls below the required level (e.g. signal degrade). MSP 1 + 1 and MS-SPRING are the examples of such type of protection. The MSP 1 + 1 and MS-SPRING are support only fixed network topology i.e. from a node to a next node and rings with max. 16 node respectively. Further in case of MS protection types complicates the building of fiber network and configuration of other nodes must be known for operation.