CHAPTER 2

LONG-HAUL WDM NETWORK WITH L-WIXC ARCHITECTURES

2.1 Introduction

The increase in traffic demand associate with new applications triggering a dramatic growth in capacity requirement for medium and long haul transport networks. Most network providers are tuning to WDM to solve the capacity problem. WDM offers the potential of an enormous increase in transmission throughput by using large bandwidth of optical fibers. Therefore, WDM is one of the best techniques for upgrading the capacity of exiting transmission links in a cost-effective ways, opening the door to new and potentially efficient all-optical routing scheme. Although the concepts for WDM started being explored in the laboratory more than two decades ago, the enabling technology for the cost-effective implementation of WDM was the creation and perfection of various passive and active optical components used to combine, distribute, isolate, and amplify optical powers at different wavelengths. Passive devices require no external control for their operation, so they are somewhat limited in their application in WDM networks. These components are mainly used to split and combine or tap off optical signals. The performance of active devices can be controlled electronically, thereby providing a large degree of network flexibility. Active WDM components include tunable optical filters, tunable sources, and optical amplifiers. Active WDM components, such as tunable optical filters, give more versatility in extracting or inserting one or more wavelengths. Tunable optical sources can be used to generate the spectrum of wavelengths needed for WDM. Finally, in long transmission distances optical amplifiers are incorporated into the link to boost the power level of a wide band of wavelengths simultaneously.

2.2 Multi-hop WDM Network Model

In this section, the basic elements of a multi-hop WDM network model is presented and analyzed based on a prominent design architecture of an OXC for the switching system and optical amplifiers for compensating the loss during long-haul transmission.

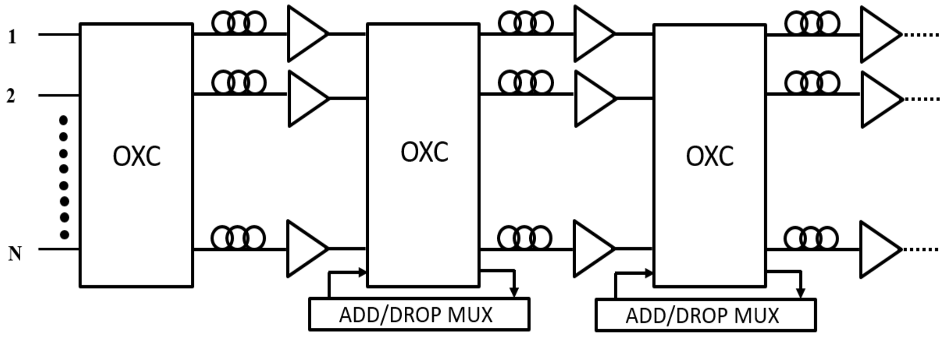

Fig. 2.1 Multi-hop WDM Communication System Model

A lightpath in the optical network consists of intermediate wavelength-routing nodes between the source and destination nodes interconnected by fiber segments. The EDFA on the input side compensates (with gain, G) for the signal attenuation along the input fiber and other losses. Each hop contains a transmitter array (TX) and a receiver array (RX) which enable local add/drop of any of the wavelengths at any of the nodes. The OXC is realized using an array of demultiplexers, optical wavelength-routing switches and multiplexers. All the demultiplexed signals on a given wavelength are directed to the same optical switch. The switch routes the signal toward the desired output port. The multiplexers combine the optical signals on all the wavelengths and pass them to the desired output port.

2.3 L-WIXC Architectures

To avoid an explosion in the cost of routing function, it is essential to introduce a new all-optical layer that can handle large bit rate with provision for restoration and wavelength switching that allow routing at the wavelength level. Achieving the goal of a multichannel path, reconfigurable all-optical network requires the employment of several enabling technologies like L-WIXC. In an all-optical wavelength-routed network of this type, an optical cross-connect switch (OXC) performs the routing and switching functions at each node. The lightpath, representing the optical layer connection between the source-destination node pairs, can be set up through the intermediate OXCs in either a wavelength-continuous (the same wavelength is used over the entire lightpath) or non-wavelength-continuous (different wavelengths may be used in different optical links along the given path) fashion. Setting up the lightpath would not only involve selecting the route to be followed but also the wavelengths to be used along the selected route. Wavelength conversions at the intermediate nodes is necessary for if non-wavelength-continuous lightpaths are to be supported. This would require the OXCs to do wavelength conversion in addition to their switching functions. The OXCs may, in turn, be classified based on their wavelength conversion capability. An OXC with full conversion capability (i.e. capable of changing any wavelength on any incoming link to any wavelength on any outgoing link) is referred to as a wavelength-interchanging cross-connect (WIXC). SSM refers to the space switching matrix used to switch the optical signals without doing any wavelength conversion. Given the cost and complexity of wavelength conversion, OXCs with limited wavelength conversion capability may also be used as these have been observed to perform almost as well as WIXCs with full conversion capability in typical network environments. These are referred to as limited-wavelength-interchanging cross-connect (L-WIXC). In an L-WIXC, a limited number of wavelength converters are shared instead of being dedicated as in a WIXC. The wavelength converters are therefore more efficiently utilized. Here, various L-WIXC architectures based on space-switching matrices, delivery and coupling switches and combinations of couplers and filters are presented in the subsequent sections.

2.3.1 L-WIXCs Based on Space Switching Matrix (SSM)

2.3.1.1 Share Per Node Architecture

This L-WIXC with the share-per-node architecture is shown in Fig. 2.2. In this architecture, the incoming channels are separated by the demultiplexers (DMUX). They are then routed by the SSM directly to the proper output (for wavelength continuous light path) or to the wavelength converters and then to the proper output (for non-wavelength continuous light paths) by a second SSM. A star coupler is used instead of multiplexer because the wavelength of the output from the second SSM is not known a priori. The first stage switching is M, (N x N+1) SSM and the second SSM is of dimension M x C, giving a total of $N^2M + MN+MC$ cross-points. In addition, there are a total of N 1 x M DMUXs, N (M+C)x 1 star couplers. The degree of wavelength converter sharing is strictly full and it represents an ideal share-per-node architecture [1].

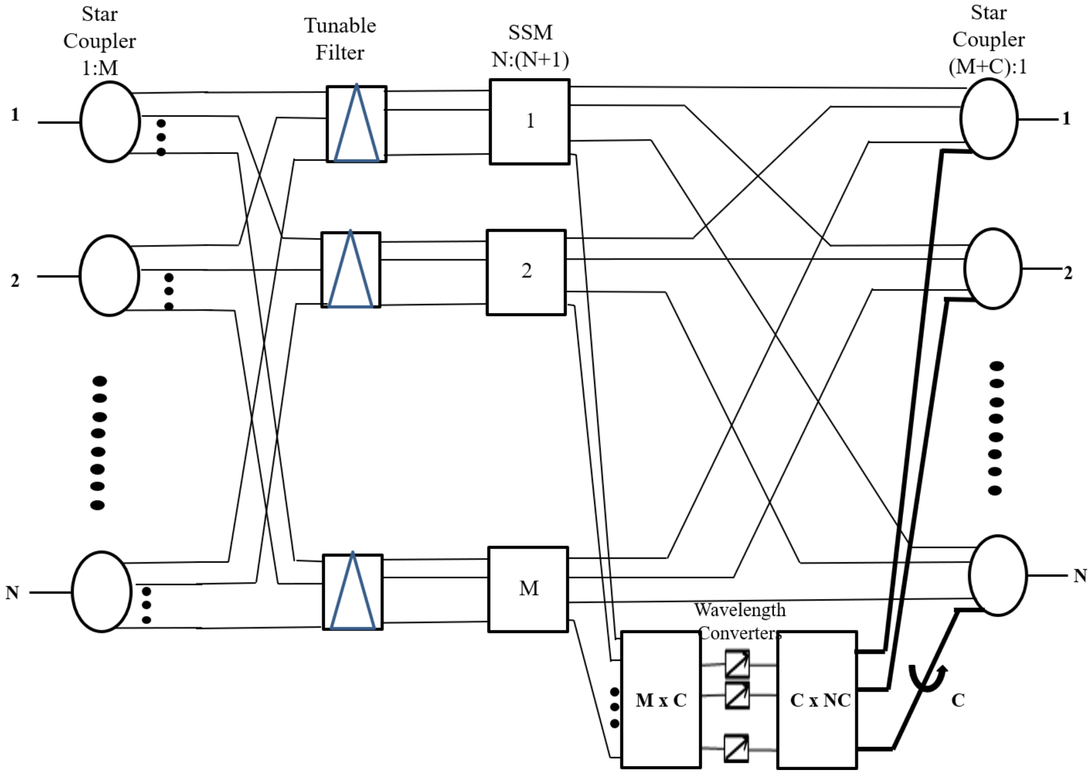

Fig. 2.2 Share per Node L-WIXC Architecture

2.3.1.2 Share Per Link Architecture

This is the other basic L-WIXCs which represents an ideal share-per-link architecture. Each input link has a dedicated set of converters that can be accessed by any channel from the input link. It only allows partial sharing of wavelength converters. This has N^2M cross point, N DMUXs and N star coupler. In this architecture, the incoming channels are separated by the demultiplexers (DMUX) and then after filtering they go through the wavelength conversion process for non-wavelength continuous light paths .Each link has C_n number of wavelength converters as a whole total C converters. For wavelength continuous light path they need not go through the wavelength conversion process. They are then routed by the SSM directly to the proper output.

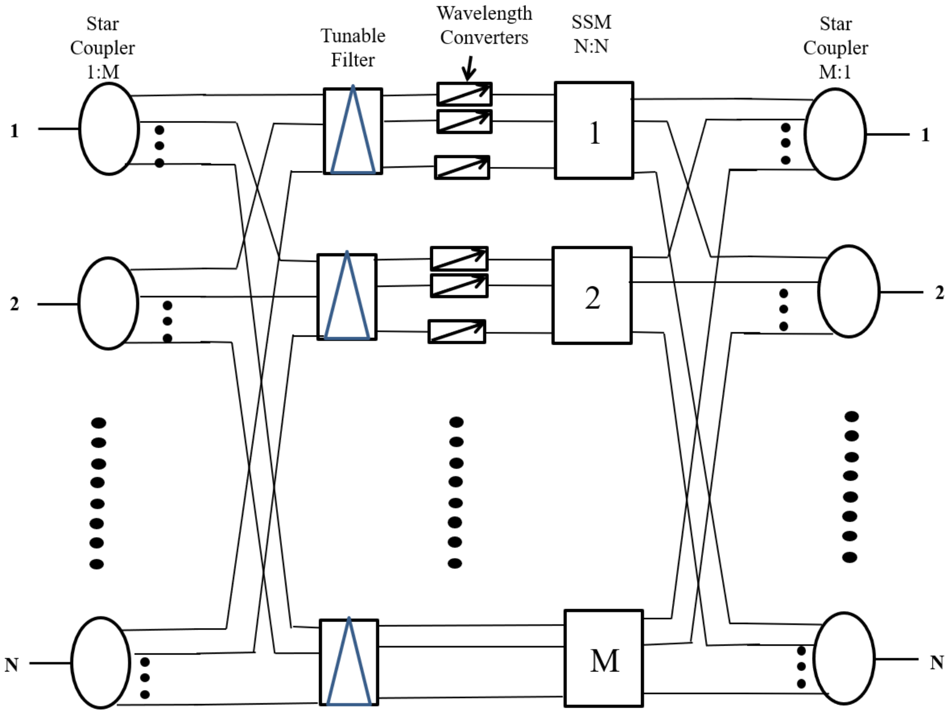

Fig. 2.3 Share Per Link L-WIXC Architecture

In terms of sharing efficiency of wavelength converters, share-per-node is the better followed by Share-per-link and WIXC the worst. In terms of complexity of switching, WIXC is the least complex, share-per-link comes next and share-per-node the most complex [1].

2.3.2 L-WIXCs Based on Delivery and Coupling Switches (DCS)

The DCS is very flexible switch allowing the presence of WDM signal obtained by multiplexing the input signal during the switch operation at its outputs . Due to combined effect of wavelength conversion and the adoption of DCS's, tunable filters at the OXC input are not needed and signal demultiplexing can be achieved by a static demultiplexer thus simplifying the input stage structure.

2.3.2.1 DCS-1 Architecture

DCS-1 supports strict full converter sharing. Those light paths from an input link that need conversion can be multiplexed to the (N + 1)th output of the corresponding DCS. The SSM located before tunable filter selects one of the outputs from the star couplers and feeds it into tunable filter to single out a particular wavelength. In DCS-1, the incoming channels are separated by the demultiplexers (DMUX).

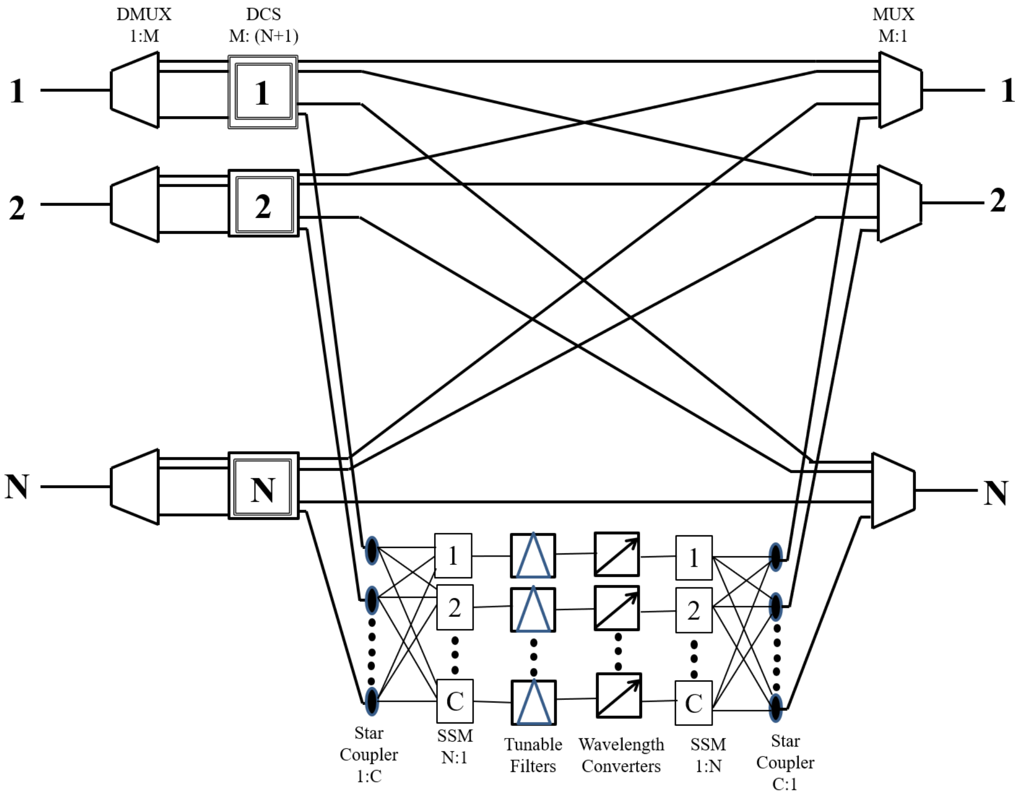

Fig. 2.4 DCS-1 L-WIXC architecture

They are then routed by the DCS directly to the proper output (for wavelength continuous light path) or to a SSM located before the tunable filter and then to the proper output (for non-wavelength continuous light paths) through wavelength conversion process. DCS-1 comprises N M x (N + 1) DCSs, C N x 1 and C 1 x N SSMs, N DMUXs, N star couplers and C tunable filters [1].

2.3.2.2 DCS-2 Architecture

This second type of DCS-based OXC has the capability of connecting multiple inputs to one output, M DCSs are sufficient to avoid blocking of the unconverted light paths. Furthermore, if a wavelength converter is available in this architecture, then any converted light path can find its route through the OXC without the link mismatch problem.

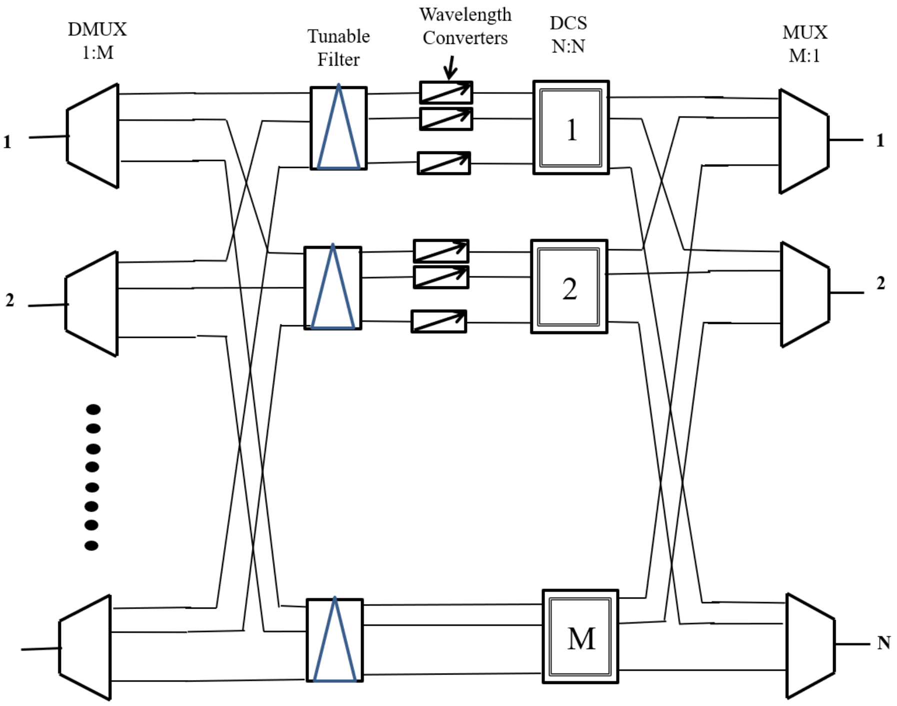

Fig. 2.5 DCS-2 L-WIXC Architecture

Wasteful occupancy can be minimized if routing unconverted light paths through the wavelength converters is avoided whenever possible. DCS-2 comprises M NxN DCSs, N 1x M input star couplers, N Mx1 output star couplers, N M tunable filter and N Cn wavelength converters. In this architecture the incoming channels are separated by the combination of input star couplers and tunable filters. Then they go through the wavelength conversion process for non-wavelength continuous light paths. For wavelength continuous lightpath they need not go through the wavelength conversion process. They are then routed by the DCS directly to the proper output [1].

2.3.3 L-WIXCs Based on Couplers and Filters

2.3.3.1 Wavelength Switching-based Architecture

In this architecture, the WDM comb from any of the N input links is delivered to each one of the N x 1 SSMs. Each SSM inhibits all but one input comb. The tunable filter at the output of the SSM will then select a channel from the comb.

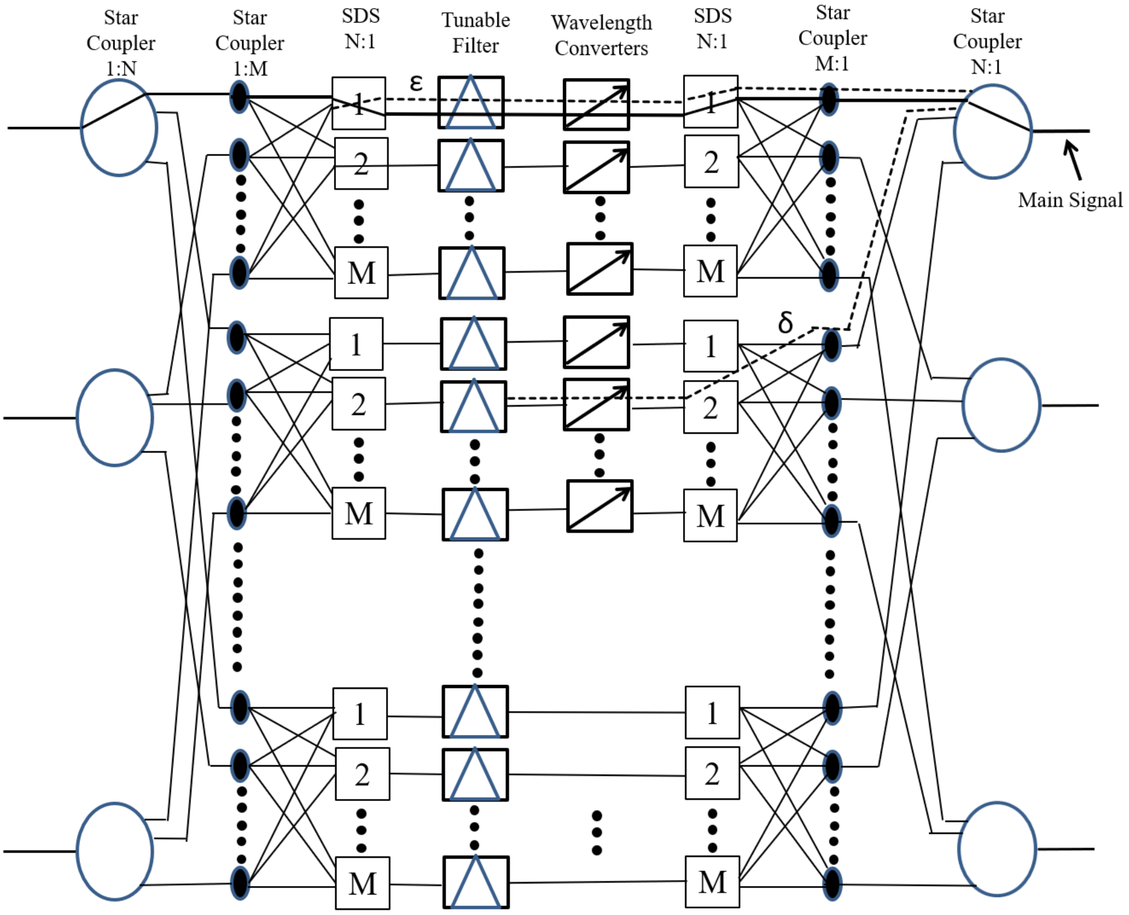

Fig. 2.6 Wavelength Switch-based L-WIXC Architecture

This architecture allows strict full sharing of wavelength converters. This architecture applies a routing scheme that searches first for routes without wavelength converters when routing unconverted light paths will minimize wasteful occupancy. This architecture also suffers from high loss due to the splitting of WDM signals but offers superior expandability and upgradeability like MWSF OXC Architecture [1].

2.3.3.2 MWSF-based Architecture

This architecture is composed of multi-wavelength selective filters (MWSF) and star couplers. An MWSF can select any combination of wavelengths using acousto-optic interaction. The MWSFs will be configured such that signals of the same wavelength are never led to the same star coupler. This limitation makes the architecture allowing only simple full sharing of wavelength converters.

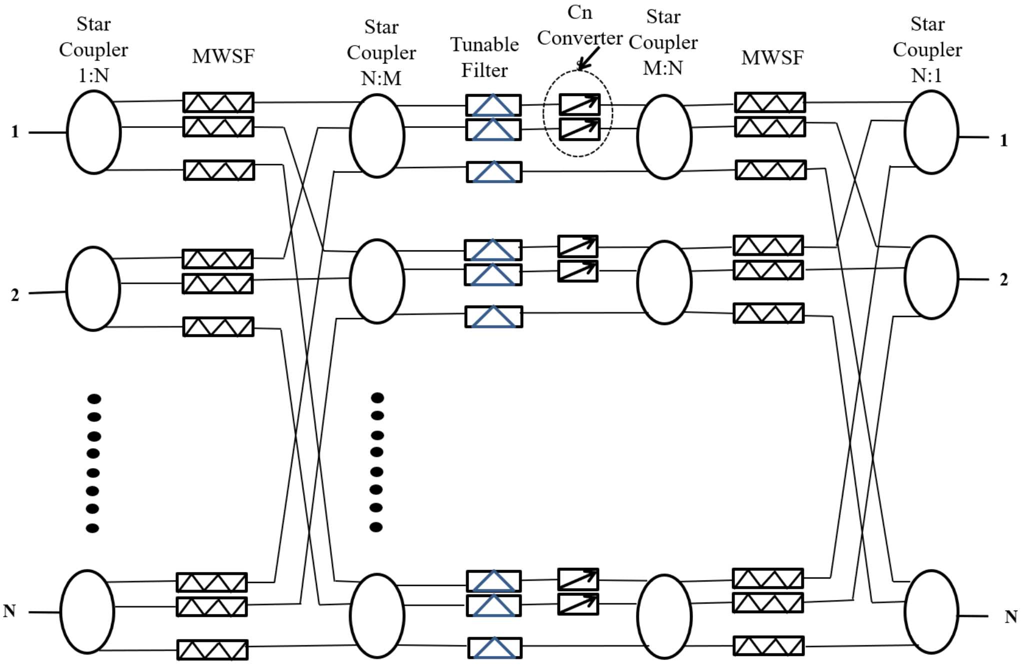

Fig. 2.7 Multi-wavelength Selective Filters (MWSF)-based L-WIXC Architecture

There are N identical intermediate modules. In each of this module, only C tunable filters followed by wavelength converters. The incoming channels are separated by the combination of input star couplers and MWSF. Then they go through the intermediate modules where the wavelength conversion process for non-wavelength continuous light paths takes place. For wavelength continuous light path they need not go through the wavelength conversion process. They are then combined at the output star couplers. This architecture suffers from high loss due to the splitting of WDM signals. However, they offer superior expandability and upgradeability compared to the other architectures of the same kind [1].

2.4 EDFAs

An optical fiber amplifier is an essential component for enabling efficient transmission of WDM signals over long distances. The active medium in an optical fiber amplifier consists of a nominally 10 to 30m length of silica or fluoride optical fiber that has been lightly doped with a rare-earth element, such as erbium(Er), praseodymium(Pr), neodymium(Nd) or ytterbium(Yb). The most popular optical-amplifier design for long-haul telecommunication applications is a silica fiber doped with erbium, which is known as an erbium-doped fiber amplifier (EDFA). The operation of an EDFA is limited to the 1530 to 1560 nm region. Usually the designation '1550 nm signals' refer to any particular optical channel in the 1530 to 1560 nm spectral band. An advantage of EDFAs is their ability to amplify multiple optical channels, provided the bandwidth of the multichannel signal is smaller than the amplifier bandwidth. For EDFAs this bandwidth ranges from 1 to 5 THz. The signal gain or amplifier gain, G of an optical amplifier is defined as,

$$G = \frac{P_{out}}{P_{in}}$$

where P_{out} and P_{in} are the output and input powers, respectively of the optical signal being amplified. To achieve this gain, based on energy conservation principles, the power of the pump laser that creates the population inversion in the EDFA must inject a power level P_p into the EDFA of at least,

$$P_p = P_s \frac{\lambda_s}{\lambda_p}$$

where λ_s and λ_p are the signal and pump wavelengths, respectively. Standard pump wavelengths for EDFAs are 980 and 1480 nm. If the pump power is less than this, the signal power drives the optical amplifier into deep saturation and the required signal gain is not met. The dominant noise generated in an optical amplifier is amplified spontaneous emission (ASE). The origin of this is the spontaneous recombination of electrons and holes in the amplifier medium. This recombination gives rise to a broad spectral background of photons that get amplified along with the optical signal. In a long transmission system, several optical amplifiers are needed to periodically restore the power level, after it has decreased due to attenuation in the fiber. Normally, the gain of each EDFA in this amplifier chain is chosen to exactly compensate for the signal loss incurred in the preceding fiber section. The accumulated ASE noise is the dominant degradation factor in such a cascaded chain of amplifiers. Interchannel crosstalk does not occur in EDFAs, as long as the channel spacing is greater than 10 kHz, which holds in practice. Thus EDFAs are ideally suited for multichannel amplification.

2.5 Summary

In this chapter, a multi-hop WDM network model is presented for the analysis of the effects of system component. Six different types of architectures of L-WIXCs are also described for the evaluation of their crosstalk contributions. Lastly, the significance of EDFA in the said network is described.