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A Review of Traffic Management in WDM Optical Networks: Progress and Challenges

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Abstract-
Due to increasing bandwidth demand, network providers are moving towards a crucial milestone in network evolution: the Optical Network. Today, the major technology that is promising to meet this high bandwidth demand of networks is optical networking. The high data rates employed by wavelength division multiplexing optical networks make them most suitable for today's growing network traffic demands. This paper reviews most of the recent research work on traffic management in WDM optical networks. Various challenges involved with optical networks are also discussed in the paper.
Keywords—Wavelength-division multiplexing (WDM); traffic; research trends; wavelength routing.

1. Introduction

Optical Wavelength Division Multiplexing is regarded as one of most feasible means of solving the bandwidth limitation problem and meeting the traffic rate demands of almost all types of networks. It enhances the processing power and data transmission rate leading to higher speed and efficiency. The potential bandwidth of single optical fiber is 50 THz [1, 2]. In WDM, bandwidth is further divided into multiple wavelength channels without overlapping the frequency and hence offering multiplexing capacity for communicating several channels simultaneously without interference.

The emerging issue in optical wavelength division multiplexing (WDM) networks is that, as more and more network users are increasing, and are using bandwidth-intensive networking applications high bandwidth transport network facilities need to be provided. The past and projected future growth of data and voice traffic reported by most telecom carriers is shown in the Figure 1. [1] In recent years, there has been an increasing amount of research activity on the traffic–management problem, both in academe and in industry. Researchers are realizing that traffic management is a practical and important problem for WDM network design and implementation and has much scope for improvement. In the past, cost factor has prevented optical components from finding their way into computers. But as optical technology matures, prices drop and the limits of miniaturization appear to have been reached and incorporating optical alternatives into computer systems. Continued advancements in optical technology may lead to end to end wavelength services.

The impact of the new optical layer in telecommunication network is astounding. It can be measured in two ways: economic impact and carriers' ability to offer new services. Optical layer technology will increase network capacity, allowing network providers to transport more than 40 times the traffic on the same fiber infrastructure. That will lead to lower prices and competition in the local exchange will ensure that bandwidth becomes more affordable.

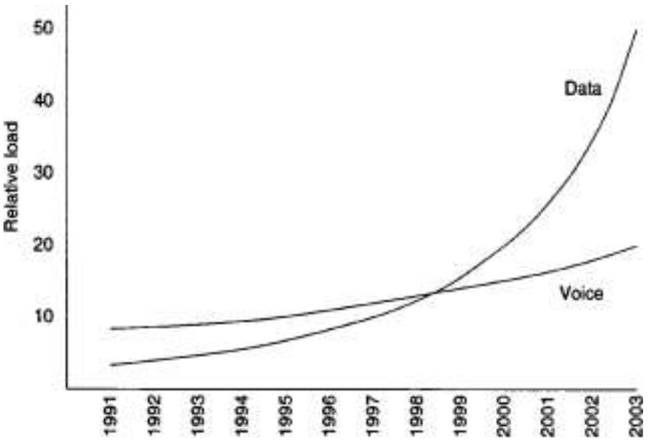

Figure 1: Past and projected future growth of data and voice traffic [1].

2. Wavelength division Multiplexing

As wavelength and frequency are closely related to each other, wavelength division multiplexing is also called frequency division multiplexing (FDM). Each WDM fiber has a certain bandwidth that refers to the range of frequencies it can carry. One advantage of WDM is that information can be sent at highest rate possible. Transfer rates are not changed in proportion to the number of users on the line. Another large benefit to WDM is that it maintains the signal integrity [6].

There are two different versions of WDM that can be defined below:

1. Coarse Wavelength Division Multiplexing (CWDM)
2. Dense Wavelength Division Multiplexing (DWDM)

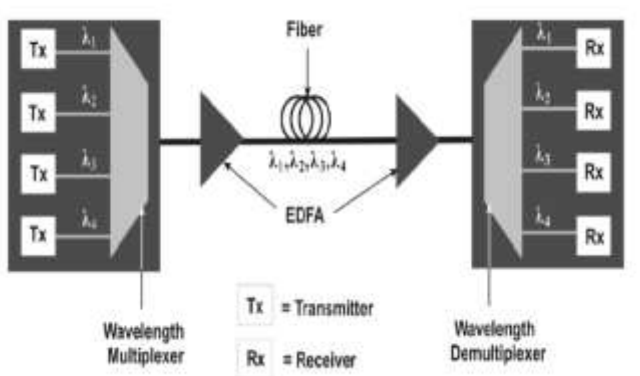

Figure 2: Wavelength division multiplexing [3]

2.1 Coarse Wavelength Division Multiplexing: Coarse wavelength division multiplexing (CWDM combines multiple signals on laser beams at various wavelengths for transmission along fiber optic cables but the number of channels is fewer than in DWDM. The channels of CWDM are 20 nanometers (nm) apart. The energy from the lasers in a CWDM system is spread out over a larger range of wavelengths than is the energy from the lasers in a DWDM system. CWDM system is less expensive because of the use of lasers with lower precision and consumes less power.

2.2 Dense Wavelength Division Multiplexing: Dense wavelength division multiplexing combines multiple signals on the same fibre, ranging up to no or 80 channels. They are further classified as: unidirectional and bidirectional DWDM. In a unidirectional system, all the wavelengths travel in the same direction on the fibre, while in a bidirectional system the signals are divided in two separate bands, with both bands travelling in different directions [3].

3. Progress in WDM Systems

Due to continued advancements in research and development optical WDM networks have matured considerably over the past few years. The recent revival of optical computing technology is due to an ever-increasing need for computational speed, coupled with the rapid increase in global demand for Internet access, television and video services, and next-generation broadband. It is anticipated that the next generation of the Internet will employ WDM-based optical backbones [1, 2]. The development phases of WDM systems can be listed as below:

A. Point-to-Point WDM Systems

In point-to-point WDM systems several channels are multiplexed at one node, the combined signals are transmitted across small some distance of fiber, and the channels are de-multiplexed at a destination node. This facilitates high-bandwidth fiber transmission. Its disadvantage is that the network and all its components must accommodate N wavelengths, which may be difficult to achieve in large network. There next others technologies were designed to overcome this problem.

B. OADM

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An optical add-drop multiplexer (OADM) multiplexes and routes different channels of light into or out of a single mode fiber. It is generally used for the construction of optical telecommunication networks. "Add" and "drop" means that device has capacity to add one or more new wavelength channels as well to drop (remove) one or more channels, passing those signals to another network path. There are three stages in OADM:

1 Optical de-multiplexer

2 Optical multiplexer,

3 A method that reconfigures the paths between the de-multiplexer and the optical multiplexer.

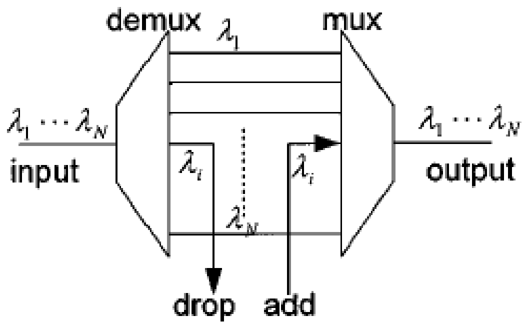

Figure 3: Internal structure of OADM

C. Optical Interconnection Systems:

In order to implement the all-optical network, a number of optical devices are required. Two of them are optical switches and optical cross connects. In optical switch, enables signals in optical fibers to be selectively switched from one optical circuit to another. An optical cross-connect (OXC) is used to switch high-speed optical signals. Core optical networks consist of OXCs and fiber links interconnecting OXCs. Examples include photonics cross connects and reconfigurable optical add/drop multiplexers. The primary benefit of all-optical devices is their greater scalability compared with optical-electrical optical devices [1, 2].

4. Recent Research Interests in WDM Networks

The major areas of research in field of optical networks are: network control and management, fault management, multicasting, physical-layer issues, IP over WDM, traffic grooming, and optical packet switching [4].We briefly examine these topics below.

4.1 Network Control and Management: There must be a control mechanism that can manage the incoming and out-going traffic in the network. Whenever there is request for connection, this mechanism should perform certain functions: first it should select a route, assign a wavelength to that route, and configure the optical switches. The wavelengths are currently being used on must also be recorded for future use. Centralized or distributed approach can be followed. Distributed approach is generally preferred. This mechanism must minimize the blocking probability of connection requests, the connection setup delays, and the bandwidth used for control messages. There distributed approaches are further of two types: link-state approach and “distributed routing approach. We describe the two approaches below.

In the link-state approach each node maintains the information regarding which wavelengths are in use. Upon the arrival of a connection request, a node utilizes this information to select a route and a wavelength and the node then sends reservation requests to each node in the route. If an intermediate node is able to reserve the wavelength on the appropriate link, it sends back acknowledgment to source node and connection is set up. If even one of the reservations is not successful, then the call is blocked.

In the distributed-routing approach, no prior information regarding wavelengths currently in use is required. A routing table is used to specify the next hop and the cost associated with the shortest path to each destination on a given wavelength. Bellman–Ford algorithm is used for constructing the table. Whenever there is connection request, a node selects the wavelength that leads to shortest distance to the destination. The destination node then sends an acknowledgment back to the source node along the reverse path. Switches are configured and data is transmitted. Negative acknowledgment is sent to source if path is unable to reserve the wavelength. The source node may then reattempt the connection on a different wavelength [4].

4.2 Fault management: If a single network link fails it can cause the failure of several optical channels. This will lead to loss of information. Various approaches to ensure fiber-network survivability have been proposed till date. Survivability is ensured by dedicating backup resources in advance, or by dynamic restoration. In dynamic restoration, spare-capacity is used to restore lost data. We list the approaches for protecting against various failures: **Protection**: Backup route and wavelength is set up in advance for the connection that we want to protect. If failure occurs we use the backup route and wavelength.

Link Restoration: Here we re-route the connections that traverse the failed link. It is responsibility of end-nodes to dynamically discover a route around the link. They need to search for new paths whenever failure occurs. If they failed to do so then connection is blocked.

Path Restoration: Here the source and the destination node both participate in recovering process. On failure both try to discover a backup route on an end-to-end basis. When route is selected then switches are configured and transmission takes place and if no new routes are found then that connection is blocked [4].

4.3 Multicasting: As the name specifies, multicasting sends single message or to multiple receivers. It enables a transmitter at a node to have many more logical neighbors. For multi-casting multicast-capable optical switches are required. Power requirements are also high.

4.4 Sparse Optical Regeneration in WDM Networks: Another important area of research in optical networks is "Transparency". For transparency to exist the physical medium should support end-to-end communication of data, independent of bit rates and signal formats. To achieve this all the information must be present in the form of phase, frequency, and analog amplitude of the optical signal. Achieving such transparency is very difficult. As signal travels through large distances if might get attenuated. In such a situation signal has to be re-generated and re-generation can follow one of following methods:

1R (Retransmission): Here the attenuated signal is retransmitted along link.

2R (Re-time and re-transmit): Along with re-transmission, the signal is sent at different time that is it is retimed.

3R (Re-time, re-transmit, re-shape): It adds re-shaping the signal along with re-transmission and re-shaping [4].

4.5 IP Over WDM: The main requirement of IP-based Internet is high bandwidth demand. IP-over-WDM networks seem to be promising technology in providing this high bandwidth demand. What distinguishes it from other technologies is that it uses wavelength routing switches and IP routers both. This network establishes high-speed optical layer connections. IP routers are connected through light-paths rather than fiber. Its advantages are

1. Less Latency
2. Automatic provisioning
3. Higher bandwidth utilization

5. Challenges ahead

Besides providing high transmission capacities optical network architecture provides the intelligence required for efficient routing. Failure recovery is also fast in these networks. The work is in the early stages and needs to be further expanded over the coming years [6].

One of the important and difficult issues involved with optical networks is **Traffic Management** for several reasons:

1. Restoration
2. Performance
3. Wavelength assignment

The optical network is implemented on the top of existing SONET architecture which provides its own restoration and protection schemes. It becomes extremely difficult to ensure that restoration schemes between the electrical and optical layer do not conflict in absence of intelligent network management scheme. Network Management Systems must be able to monitor signal performance for each wavelength. Network Management Systems for must help the service providers in troubleshooting the network. It is very crucial task to manage and provide new services to customers. Provisioning end-to-end services is difficult.

Desirable speeds and **quality of service** are important issues in these networks to be handled. Providing **security** is another matter of concern. Optical firewall named WISDOM is expected to provide security. The WISDOM firewall acts as a kind of primary, high-speed filter. It is able to carry out optical packet recognition, inspection and manipulation of data streams, incorporating features of parity checking, flag status and header recognition. Research is being done in generation of all-optical devices such as firewalls and intrusion prevention systems that will make optical networks secure. Hence, we can say traffic management, providing desirable speeds, quality of service and providing security are challenges ahead in field of optical networks.

6. Conclusion

This paper outlines the progress in WDM optical networks for managing high rate traffic. It also summarizes the key challenges such as traffic management, providing desirable speeds, ensuring security etc in optical networks. Optical networking is emerging technology and there is much future scope for the improvement in managing high rate traffic in large scale optical networks.

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