DOI: 10.21917/ijct.2010.0005

A SURVEY ON WAVELENGTH DIVISION MULTIPLEXING (WDM) NETWORKS

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Abstract
Communication networks have emerged as a source of empowerment in today's society. At the global level, the Internet is becoming the backbone of the modern economy. The new generations in developed countries cannot even conceive of a world without broadband access to the Internet. The inability of the current Internet infrastructure to cope with the wide variety and ever growing number of users, emerging networked applications, usage patterns and business models is increasingly being recognized worldwide. The dynamic growth of Internet traffic and its bursty nature requires high transmission rate. With the advances and the progress in Wavelength Division Multiplexing (WDM) technology, the amount of raw bandwidth available in fiber links has increased to high magnitude. This paper presents a survey on WDM networks from its development to the current status. Also an analysis on buffer size in optical networks for real time traffic was performed.

Keywords:
Bandwidth, Buffer size, Power consumption, WDM, Optical packet switching, Optical networks.

1. INTRODUCTION

Although the Internet has successfully enabled multiple waves of innovation, novel societal and commercial uses are continuing to push the original Internet architecture to its limits [28]. The enormous increase in online content and the requirement of providing universal access to broadband Internet services is already stretching the capabilities of current technologies to their limit. New applications require networks with well-known and predictable characteristics and behavior.

There are many challenges seen as driving forces towards the future Internet. Some of these challenges are listed below:

- Available bandwidth per user/device will continue to grow
- Heavy increase in content and quality of content
- Huge increase in the number of user
- Large data flow transfer between users, remote instrumentation, and computing/data centers
- Energy-efficient networking

Wavelength Division Multiplexing (WDM) allows single optical fiber to carry traffic on multiple optical channels by assigning to each channel a unique wavelength in which the corresponding traffic is transmitted. Each node in a WDM network is capable of optically switching traffic on any of the wavelengths supported by the network. This allows the creation of clear end-to-end optical channels that span multiple physical fiber hops but retain all the advantages of optical transmission over a continuous span of fiber [19].

The use of WDM allows the utilization of the large bandwidth inherent in optical fiber. In some cases, the fiber has been used as a simple alternative to copper wire. This means that only a single wavelength is used to carry information over a fiber and the fiber then acts as a point-to-point link of a given bandwidth. With WDM, each wavelength can utilize bandwidths comparable to that which the entire fiber was providing. With the further use of wavelength routing or virtual topologies, the bandwidth available to traffic goes up further.

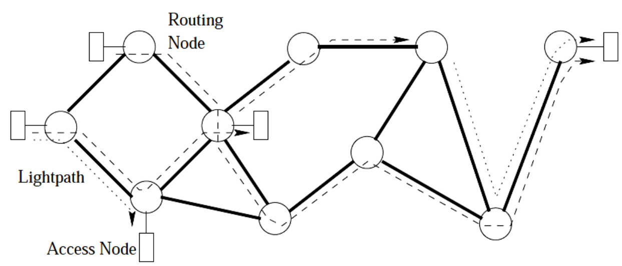

Fig.1. A WDM Network

Figure 1 shows the communication by a clear channel between different nodes in simple physical networks [31]. The dotted lines indicate the lightpaths. With the use of different wavelengths two lightpaths can share a common physical link. The updation from point-to-point fibers to WDM and then virtual topologies can be in an incremental manner.

The virtual topology provides a certain measure of independence from the physical topology, because different virtual topologies can be set up on the same physical topology, though the set of all virtual topologies that can be set up is constrained by the physical topology. In setting up a virtual topology, the usual considerations are delay, throughput, equipment cost and reconfigurability.

The available capacity in optical network infrastructure can be increased by the recent development of new transmission and switching technologies [24]. A wavelength channel has a transmission capacity of several Gbits/s for WDM and this high transmission capacity may cause information loss even if a single fiber is disrupted. If a failure occurs in a network then congestion takes place and the network gets interrupted. To recover the blocked connections in the network within an acceptable time limit [22].

Because of high transmission efficiency when considering IP traffic, optical packet switching has gained particular attention in recent years. For these developments the system requires fast optical switches, wavelength converters and optical buffers.

Optical buffers are realized by fiber delay lines, since optical random access memories are not feasible. The total power consumption can be compromised by the use of optical amplifiers with the highly attenuated long fibers in fiber delay lines.

The remaining paper is organized as follows. Section 2 describes about the traditional optical networking. Section 3 describes in detail about the related work in WDM optical networks. Section 4 analyses the performance of optical buffer size in real time traffic. Section 5 gives the future direction in the field of WDM optical networks. Finally conclusion is added in section 6.

2. TRADITIONAL OPTICAL NETWORKING

Literature depicts that there are two generations of development in the Optical Network. Initially to meet the increasing telephony traffic demands optical networking was the prospect of tapping the vast usable bandwidth of optical fiber of 30 THz [8].

First generation development of optical fiber started in the 1970s and employed optical fibers as replacements for copper cable links. In this generation, informational bottlenecks were preempted at transmission links, but loomed at network nodes whose operations were constrained by the speed of electronics.

Second generation emerges from the year 1990 onwards. This employs optical networking devices in addition to the optical fiber. The data traffic served by these networks is characterized by detailed statistics like governing transaction length and burstiness. The first generation optical fiber networks are quite different from the telephony traffic in the quality of service demands. This is similar to traffic arising from the heavy-tailed nature of data transactions [5].

Table 1 Bandwidth requirements for future access networks

Services	Bandwidth Consumption
SDTV	2 Mb/s per channel
HDTV	8 Mb/s per channel
3D SDTV	63 Mb/s per channel
3D HDTV	187 Mb/s per channel
Basic HIS	5 Mb/s average
Gaming	10 Mb/s average
Multimedia surfing	8 Mb/s average
Video-Conferencing and learning	3 Mb/s per session
Telecommunication	4 Mb/s average
Voice-over IP	110 Kb/s

Table 1 shows the bandwidth requirements for some sample services [9]. Besides a singular session for a specific service, a number of terminals can be online at the same time, connected to a single access link.

By the year 2005, the traffic increase rate fell to 40%-50% every year, while router throughput became almost saturated due to the high IP related processing burden and the energy issues. The traffic growth rate of 40% a year is still huge and results in traffic that is 30 time the present traffic in 10 years [12].

Network protection and restoration functionality is one of the essential requirements for next-generation networks that will have huge capacities, since a small time of outage in these networks will cause a large amount of user traffic loss [27]. Network survivability is the ability of a network to maintain the continuity of critical services to end users in the presence of network failures and can be realized through connection protection and restoration [7]. All the layers above the optical layer will have full protection functions of their own. Because of the speed, cost-effectiveness, and efficiency in dealing with certain types of failure, optical layer protection and restoration have an important role in network survivability.

3. RELATED WORK

Ramamurthy et al [20] presented Integer Linear Program (ILP) formulations for the routing and wavelength assignment problem are developed for a static traffic demand for both path and link protections schemes. Ho et al [11] proposed that the networks primary path is divided into several overlapped segments and the backup path for each sub-domain can be calculated individually. Redundant trees are used to provide rapid recovery and are presented by Medard et al [16]. Their algorithm constructs two trees in such a fashion that each destination vertex is connected to the source by at least one of the directed trees when any vertex in the graph is eliminated.

Anand et al [1] described the performance of sub-path protection scheme in terms of capacity utilization and recovery time, compared with path and link protection schemes. Zang et al [30] developed an on-line network control mechanism to manage the connections in WDM mesh networks using path protection schemes. They use the two-step approach to route the connections. A new multiplexing technique called primary-backup multiplexing is proposed by Mohan et al [18] to improve resource utilization. This technique allows a primary lightpath to share the same wavelength with some backup lightpath.

Sen et al [23] proposed to use the link-disjoint path pair, whose longer path is shortest among all such pairs of paths, for path protection so that the delay on the backup path is minimized. They prove that the problem of finding such a pair of paths is NP-complete, and they use the one-step approach as the approximation solution. Xin et al [29] attempted to optimize the network resource utilization of each call by minimizing the overall cost of the primary and backup path. The paths are selected from K precomputed candidate route pairs.

Hybrid multiplexing and demultiplexing schemes with the capability to integrate microwave and millimeter-wave frequency radio-over fiber signals in a WDM passive optical network infrastructure was proposed by Masuduzzaman et al [15]. The proposed schemes exploited the benefits of a spectrally efficient wavelength interleaving technique and enhance the performance of optical millimeter-wave signals without employing an additional device. The schemes are demonstrated experimentally with simultaneous transport of 1 Gbit/s baseband, 2.5 GHz microwave, and 37.5 GHz millimeter wave signals that have the potential to converge last-mile optical and wireless technologies.

Clustering is a proven effective approach for self-organizing a network into a connected hierarchy. Chen et al [4] viewed clustering as a hub and spoke model as in the airline industry. Assuming static traffic, a heuristic based on the K-Center problem to create K virtual stars of nodes was proposed. Hideaki et al [10] proposed a 640 Gbit/sport optical packet switch prototype consisting of multiple optical label processors, polarization-independent plomb lanthanum zirconate titanate waveguide optical switches, optical fiber-delay line buffers and a parallel pipeline buffer manager.

Urban et al [26] presented a hybrid ring-shaped wavelength division multiplexing time division multiplexing passive optical network that is capable of providing bandwidth on demand at high bit rates in a transparent and dynamic manner. Steven Fortune [25] presented a dynamic programming algorithm that chooses the minimum-cost amplifier placement subject to bounds on introduced nonlinear phase shift and noise.

By introducing intelligent control, agile all-optical networks can serve dynamic and flexible bandwidth on demand. A protection scheme for single-duct ring networks is proposed by Wei et al [27] followed by a rearrangeable bandwidth allocation scheme to decrease blocking in critical connection setup. The survivable dual-duct ring infrastructure proposed will have survivability for the type of network in order to improve the efficiency of network resource utilization and signal quality.

The main limiting factors for scaling the current architectures are the power consumption. This approach has capacities of hundreds of terabits or even petabits per seconds. Slavisa Aleksic [24] addressed power consumption issues in high capacity switching and routing elements. Also they examined different architectures based on both pure packet-switched and pure circuit switched designs. All these were done by assuming either all electronic or all optical implementation. The implementation results show that optics is more power efficient; especially circuit switched architectures have a low power consumption.

Mohammad et al [17] addressed both problems in non-splitting capabilities and in splitting networks, where the nodes do have optical splitting capabilities. The cost of a WDM network is dominated by the cost of higher-layer electronic ports. Based on the observations from optical solutions, Mohammad et al developed a heuristic approach for each network by relaxing and simplifying its corresponding mixed integer linear program.

4. ANALYSIS OF BUFFER SIZE

Buffer size states the amount of buffering needed at an output interface is equal to its delay-bandwidth product.

The buffer size can be obtained by,

$$B = RTT \times C \qquad (1)$$

where, B is the buffer size, RTT is the round trip time of a real time TCP connection and C is the output capacity. This equation ensures that the output link is utilised 100% of the time. For example, a typical round trip time of a real time TCP connection having 250 ms and with output capacity of 40 Gbps, then the buffer size will be 1.25 GB. Normally, the use of large buffer size complicates the router design, which increases power consumption and makes them very expensive.

In network regions where the buffer size lies typically between 10 to 30 KB, the UDP packet loss tends to increase with the larger buffer size. This loss behaviour for UDP traffic seems to occur due to its interaction with TCP's congestion control mechanisms. However, for buffer size that are below a critical value, UDP can benefit by time-sharing the buffers with TCP.

Normally, the UDP trace has an average rate o about 5 Mbps, constituting roughly 5% of the bottleneck link rate, which is operated at 100 Mbps. Measurement based studies show that TCP is a predominant transport layer protocol, constituting in excess of 90% of the Internet traffic, with UDP accounting for the remaining 5% to 10% [2].

When the buffers at the bottleneck router are extremely small in the range of 1 to 10 KB, the congestion window of all the TCP flows remain extremely small. From the surveys, it can be concluded that the buffers are minimally used by TCP, and UDP has access to the entire buffer space for the most part. An extra buffer of one kilo Byte can add significant amount of optical switch. The router designers and network providers should be aware of negative returns on extra buffers [3].

5. FUTURE DIRECTIONS

An analysis on future service scenarios predict that the traffic growth in the optical network will be in excess of 50% per year. In order to economically sustain this level of growth, the network will require cost reduction in the price per bandwidth that has not been achievable by technological development alone [6]. Optical WDM has been shown to be successful in providing virtually unlimited bandwidth to support an ever increasing amount of traffic for future optical networks. Future optical networks, especially the metropolitan networks and local networks are expected to flexibly and cost effectively satisfies a wide range of applications having time-varying and high bandwidth demands and stringent delay requirements. Such facts result in the need to exploit the optical packet-switching paradigm that takes advantage of efficient sharing of wavelength channels among multiple connections [14].

In future, Internet will be everywhere like air, always on like water and electricity [13]. Traffic on the Internet has been growing dynamically, and the explosion of data traffic over the Internet is bursty in nature. Researchers in this field suggested that traffic generated by web browsers, world wide-area transmission control protocol connections and variable bit-rate video sources are all self-similar. Inorder to provide ubiquitous Internet Protocol services the optical internet network should provide new and efficient incentives to build a flexible and bandwidth abundant fiber optic network infrastructure.

Another characteristic of a future proof network, such as reliability, survivability and coverage, can be improved by a network topology that is scalable and enables traffic routing. The cost efficiency of the network is enhanced by the integration of optical functions in photonic chips, which enables mass production to eventually provide a lower cost per devices [21].

6. CONCLUSION

This paper discussed the issues and trends concerning power consumption of future high-capacity optical networks. Surveys concluded that circuit-switched nodes consume less than 10% of the power consumed by optical packet-switched architectures. Moreover, electronic circuit-switched designs consume 43% less power than packet-switched ones. In order to overcome the scalability limitations of core network nodes due to high complexity and large power consumption of current approaches, it is an important challenge to fine a well-suited and feasible network concept that will be able to provide both high performance and low power consumption.

REFERENCES

[1] Anand V., Chauhan S. and Qiao C., "Sub-path protection: Anew framework for optical layer survivability and its quantitative evaluation", Department of Computer Science and Engineering, State University of New York at Buffalo, Technical Report2002-01, 2002.

[2] Arun Vishwanath and Vijay Sivaraman, "Sharing small optical buffers between real-time and TCP traffic", Journal of Optical Switching and Networking, Elsevier, 2009, doi: 10.1016/j.osn.2009.08.006.

[3] Bernasconi P. et al., Architecture of an Integrated Router Interconnected Spectrally (IRIS), in the proceedings of IEEE High Performance Switching and Routing, Poland, June 2006.

[4] Chen B, Rouskas G. N and Dutta R., "Clustering and hierarchical traffic grooming in large scale mesh WDM networks", in Proceedings of 11th Conference on Optical Network Design and Modeling, Athens, Greece, pp. 249-258, 2007.

[5] Crovella M. E. and Bestavros A., "Self-similarity in world wide web traffic evidence and possible causes", IEEE/ACM Transactions on Networking, Vol. 5, No. 6, pp. 835-846, 1997.

[6] Davey R. P. and Payne D. B., "The future of optical transmission in access and metro networks – an operator's view", in 31st European Conference on Optical Communication, pp. 53-56, IEEE, 2005.

[7] Gerstel O. and Ramaswami R., "Optical layer survivability: a services perspective", IEEE Communication Magazine, Vol. 38, No. 3, pp. 104-113, March 2000.

[8] Guy Weichenberg, Vincent W. S. Chan and Muriel Medard, "Design and Analysis of Optical Flow-Switched Networks", Journal of Optical Communication and Networking, Vol. 1, No. 3, pp. B81-B97, August 2009.

[9] Heron R. W., Pfeiffer T., Van Veen D. T., Smith J. and Patel S. S., "Technology innovations and architecture solutions for the next-generation optical access network", Bell Systems Technology Journal, Vol. 13, pp. 163-181, 2008.

[10] Hideaki Furukawa, Naoya Wada, Hiroaki Harai and Tetsuya Miyazaki, "Development of a 640-Gbit/s/port Optical Packet Switch Prototype based on Wide-Colored Optical Packet Technology", Journal of Communication and Networking, Vol. 1, No. 3, pp. B30-B39, August 2009.

[11] Ho P. H. and Mouftah H. T., "SLSP: a new path protection scheme for the optical internet", Proceedings of OFC'01, Anaheim, CA, Vol. 2, March 2001.

[12] Ken-ichi Sato and Hiroshi Hasegawa, "Optical Networking Technologies that will Create Future Bandwidth-Abundant Networks", Journal of Optical Communication and Networking, Vol. 1, No. 2, pp. A81-A93, July 2009.

[13] Li-Mei Peng and Young-Chon Kim, "Investigation of the Design of MAC Protocols for TT-TR-based WDM Burst-Switched Ring Networks", Journal of Optical Communication and Networking, Vol. 1, No. 2, pp. A25-A34, July 2009.

[14] Maria C. Yuang, Po-Lung Tien and Shih-Hsuan Lin, "Pseudo-Banyan Optical WDM Packet Switching System with Near-Optimal Packet Scheduling", Journal of Optical Communication and Networking, Vol. 1, No. 3, pp. B1-B14, August 2009.

[15] Masuduzzaman Bakaul, Ampalavanapillai N., Christina L., Dalma N. and Rod W., "Spectrally efficient hybrid multiplexing and demultiplexing schemes toward the integration of microwave and millimeter-wave radio-over fiber systems in a WDM-PON infrastructure", Journal of Optical Networking, Vol. 8, No. 5, pp. 462-487, May 2009.

[16] Medard M., Finn S. G., Barry R. A. and Gallager R. G., "Redundant trees for preplanned recovery in arbitrary vertex-redundant or edge-redundant graphs", IEEE/ACM Transactions on Networking, Vol. 7, No. 5, pp. 641-652, Oct. 1999.

[17] Mohammad A. Saleh and Ahmed E. Kamal, "Many-to-many traffic Gromming in WDM Networks", Journal of Optical Communication Networking, Vol. 1, No. 5, pp. 376-391, October 2009.

[18] Mohan G., Siva Ram Murthy C. and Somani A. K., "Efficient algorithms for routing dependable connections in WDM optical networks", IEEE/ACM Transactions on Networking, Vol. 9, No. 5, pp. 553-566, Oct. 2001.

[19] Prashant Iyer, Rudra Dutta and Carla D. Savage, "Minimizing transceivers in optical path networks", Journal of Optical Networking, Vol. 8, No. 5, pp. 454-461, May 2009.

[20] Ramamurthy S. and Mukherjee B., "Survivable WDM mesh networks, part I-protection", Proceedings of IEEE INFORCOM'99, Vol. 2, (New York), pp. 744-751, March 1999.

[21] Rubenstein R., "Optical integration moves back onto the agenda", Fiber System Eur., pp. 14-17, May 2006, http://fibresystems.org/cws/article /ar ticles/24945.

[22] Rubenstein R., "Optical integration moves back onto the agenda", Fiber System Eur., pp. 14-17, May 2006, http://fibresystems.org/cws/article /ar ticles/24945.

[23] Rui Dai, Lemin Li, Sheng Wang and Xiaoning Zhang, "Survivable and traffic-oblivious routing in WDM networks: valiant load balancing verses tree routing", Journal of Optical Networking, Vol. 8, No. 5, pp. 438-453, May 2009.

[24] Sen A., Shen B. H. and Bandyopadhyay S., "Survivability of lightwave networks-path lengths in WDM protection scheme", Journal of High Speed Networks, Vol. 10, pp. 303-315, 2001.

[25] Slavisa Aleksic, "Analysis of Power Consumption in future High-Capacity Network Nodes", Journal of Optical Communication and Networking, Vol. 1, Issue 3, pp. 245-258, August 2009.

[26] Steven Fortune, "Algorithmic Choice of Optical Amplifiers Respecting Noise and Nonlinearity Constraints", Journal of Optical Communication Networking, Vol. 1, No. 5, pp. 366-375, October 2009.

[27] Urban P. J., Huiszoon B., Roy R., M. M. de Laat, Huijskens F. M., Khoe G. D., Koonen A. M. J., and H. de Waardt, "High-bit rate Dynamically Reconfigurable WDM-TDM Access Network", Journal of Optical Communication and Networking, Vol. 1, No. 2, pp. A143-A159, July 2009.

[28] Wei Yang, Sofia A. Paredes, Henry Schriemer and Trevor J. Hall, "Protection of Dynamic and Flexible Bandwidth on Demand in Metro Agile All-Optical Ring Networks", Journal of Optical Communication and Networking, Vol. 1, No. 2, pp. A160-A179, July 2009.

[29] Wosinksa L., Simeonidou D., Tzanakaki A., Raffaelli C., and Politi C., "Optical Networks for the Future Internet: Introduction", Journal of Optical Communication and Networking, Vol. 1, No. 2, pp. F11-F13, July 2009.

[30] Xin C., Ye Y., Dixit S. and Qiao C., "A joint lightpath routing approach in survivable optical networks", Proceedings of the SPIE Asia-Pacific Optical and Wireless Communications, Vol. 4585, pp. 139-146, Nov. 2001.

[31] Zang H and Mukherjee B., "Connection management for survivable wavelength-routed WDM mesh networks", SPIE Optical Networks Magazine, Vol. 2, No. 4, pp. 17-28, July 2001.

[32] Rudra Dutta and George N Rouskas, "A Survey of Virtual Topology Design Algorithms for Wavelength Routed Optical Networks", NSF under grand NCR-9701113, North Carolina State University, Raleigh, May 12, 1999.