Resource Allocation in the Next Generation Core Network with Dense Wave Division Multiplexing (DWDM) Backbone

Tiwonge Kawonga and Hu Hanrahan
Centre for Telecommunication Access and Services*
University of the Witwatersrand, Johannesburg
Email: {t.kawonga, h.hanrahan}@ee.wits.ac.za
Tel: +27 11 7177261; Fax: +27 11 403 1929

Abstract—The Next Generation Network is a multiservice network. It is an open architecture which allows easy and quick development of services. In addition to this factor, an increase in the number of data services creates a high demand for bandwidth. Dense Wave Division Multiplexing (DWDM) is a technology that will deliver the needed bandwidth. This paper formulates an approach of migrating the existing transport network to DWDM. The main aim is to reduce blocking probability to almost zero at the optical layer while minimising the cost of equipment. Quality of Service is also considered in allocating resources.

Index Terms—Next Generation Network, Wavelength Division Multiplexing, Mesh, Ring, Quality of Service (QoS), Class of Service

I. INTRODUCTION

The Next Generation Network (NGN) is packet based network [8]. It is based on open standards which allows interoperability between different protocols and technologies. The five layered architecture defined by Centre for Telecommunication Access and Services (CeTAS) [1] is shown in Fig 1.

![Fig. 1. Next Generation Network Architecture](image)

The Application Layer allows third party application developers to create and deploy new services easily and quickly. The application layer is supported by Service Capability Function Layer as shown in Fig. 1. The application layer uses an Application Programming Interface (API) to communicate with the Service Capability Functionality (SCF) [1]. The API allows the reuse of logic for different applications and services. The SCF layer provides functionality, such as call and session control to the application layer [1]. Below the SCF is the Network Service Capability Function Layer (NSCF). The NSCF provides servers which adapt each request, such as connection set up for a Voice over IP (VoIP) service to switching and transmission requirements. Other servers provide functionality such as operations management of the system [1][8][9]. The last two layers are the Switching Control and Management Functionality (SCMF) and Transmission Control Management Functionality (TCMF) layers. These two layers control network elements (switching, routing and transmission equipment). The traffic from the upper layers create demands on a transport network. Even though traffic can be estimated from other factors, it will be difficult to predict traffic demands in this dynamic service creation environment. Services may have varying life cycles lengths. And lastly, different services create different traffic patterns. These challenges cannot be ignored when considering migration from existing transport systems such as Synchronous Digital Hierarchy (SDH) and Synchronous Optical Network (SONET) to Dense Wavelength Division Multiplexing (DWDM).

The objective of this paper is to formulate a traffic flow problem which minimizes the cost of transmission infrastructure to meet stated demand for a telco operator migrating from existing transportation technologies such as SDH to DWDM. Inputs to the resource allocation problem are network topology of DWDM and traffic demands. The outputs are allocation of wavelengths to traffic demands, equipment required and the cost of equipment.

The remaining parts of the paper cover the following areas: Section II presents Wavelength Division Multiplexing transport system. Section III looks at the suitability of mesh and ring network topology for the core network. Section IV presents the process of traffic grooming for optimum utilisation of resources and shows how grooming can help to meeting Quality of Service (QoS) Service Level Agreements (SLA) during restoration. Section V covers how resources are allocated in the core network and optimization techniques used to minimize the cost. Section VI presents the conclusions.
II. WAVELENGTH DIVISION MULTIPLEXING (WDM)

Many network providers are currently using Internet Protocol (IP), Asynchronous Transfer Mode (ATM) or Frame Relay (FR) as transport protocols. Others have migrated to Multiprotocol Label Switching Protocol (MPLS). Relative to IP, ATM and MPLS provide a better management framework for traffic but cannot provide additional bandwidth being demanded by applications. DWDM extends the capacity of Wavelength Division Multiplexing (WDM) and makes more bandwidth available at transport layer. In this way, the upper layer protocols take advantage of the bandwidth provided by the introduction of DWDM.

A. Transport System Layers

We use the following layers [11] to define the such a network: physical layer (fibre span), wavelength division (DWDM) layer, Optical Cross Connect (OXC) and packet network (IP, ATM, FR, SONET) layer. Fig. 2 shows nodes A, B, C, D and E. The packet (non optical) network layer represents nodes used by the existing transport systems, OXC layer, Wavelength Division Multiplexing (WDM) and optical fiber layer are introduced for optical transport systems.

B. Overview of WDM

Different technologies are used in the core network backbone. WDM is the transmission of more than one optical signal in the same direction using different wavelengths over the same strand of cable. High capacity WDM systems are known as DWDM [19]. DWDM has the potential to provide much needed bandwidth to support the ever growing bandwidth demand for data services [19]. Lower cost per bit is achieved if more than eight wavelengths are used in WDM [19]. An Optical Transport System (OTS) is a pair of WDM terminals that multiplex and demultiplex wavelengths onto a single fiber [11] as shown in Fig. 2. Each OTS is bidirectional and uses a pair of fiber cables, one in forward direction and the other in reverse direction. A link can have several pairs of OTS. Channel cards are added to a WDM system when needed and a system capable of handling many channels, for example 96 channels, can be installed where only 8 channels are active [19]. Even though initial costs may be high, WDM is a better technology for the NGN environment where services can produce an unpredictable, dynamic demand. New channels would be added and activated on demand. Initial planning provides capacity of the system and not only for active cards. The required units to install a DWDM system are WDM unit, OXC unit, channels of WDM, units ports of OXC unit and amplifiers [19].

III. SELECTING BETWEEN RING AND MESH CONFIGURATION

Several factors are considered when selecting between mesh and ring network topologies. The main focus is on cost effective layout for given traffic and resources, reliability and scalability. The clients of the optical layer e.g. SDH can have either mesh or ring topology. However, for the core network, we need to identify the topology that will optimize network performance. The network should also provide QoS under normal operation and when restoration or protection path is used. The main criteria for evaluating selection between mesh and ring topology are [12][13]: migration and scaling, speed of deployment, utilization, restoration, traffic size, provisioning of new services and cost.

A. Ring Topology

In a ring topology, the nodes are interconnected in a ring by links. Traffic flows from source node to destination node along the ring. The traffic gets into and out of the ring through Add and Drop Multiplexers (ADM, and OADM for optical networks). A ring topology is very suitable in SONET and SDH networks when deployed in metro and regional networks. The ring networks provide high reliability and very fast restoration in metro and regional networks [12]. It has been shown that for the same number of nodes and with low traffic volume, the ring network requires smaller number of wavelengths to carry traffic around the ring network compared to mesh network and hence ring network requires fewer resources compare to mesh network [12]. In this case, the ring network provides best solution. However, with increase in distance between nodes and large volume of traffic in the core network, a ring network suffers from scalability and increased cost [12]. The increase in distance between nodes in the core network necessitates additional signal conditioning along the network. Since the whole data traffic is carried around the ring network instead of using direct connection from source to destination node [12].

B. Mesh Topology

The mesh topology allows nodes to be directly connected. The mesh topology is preferred to a ring in the core
network. For high traffic (such as in a core network compared to metro and regional networks), a mesh network uses less wavelengths compared to ring network [12]. It allows flexible provisioning of bandwidth and QoS [12] which fits in very well with the NGN service architecture, whose main objective is quick and easy creation and deployment of services thereby producing dynamic traffic demand patterns. With increase in data services partly contributed by the Internet, bandwidth demand is likely to be constantly increasing [13]. Mesh networks have an added advantage over ring in that dynamic provisioning and deterministic shared protection is supported [13]. Mesh requires less resources because it is possible, in most cases, to have direct connection between nodes.

IV. TRAFFIC GROOMING AND QoS

Grooming is the process of multiplexing lower bit rate traffic into higher bit rate traffic to make optimum use of transmission channel bandwidth. Grooming enables traffic to be added to or dropped from links. It also defines the level of granularity of traffic that can be added or removed from a link. Grooming is used in SDH, SONET and many other network carriers such as ATM and MPLS.

The objective of grooming is to bundle packets for cost effective transportation through the network. Granularity refers to the size of low rate traffic sources that can be multiplexed into a wavelength or high rate circuit. For example, a 64 Kbits/s (E0) stream of data multiplexes (is groomed) into a 2 Mbit (E1) stream and 64 E1 streams are groomed into an E4 (139.64 Mbits/s) or 1 STM-1 SDH. Groomed traffic is carried in a bundle from source node to destination node using one wavelength or more if wavelength conversion is supported.

A. WDM Equipment Cost

Traffic grooming plays a vital role in determining the cost of the network. At the optical layer, grooming depends on the source of traffic. If the source is an SDH network, source streams are in the form of Virtual Containers (VC) e.g. VC-4. The virtual containers are multiplexed (groomed) into Synchronous Transfer Modules (STM) e.g. STM-1 (155 Mbits/s). The traffic is multiplexed before a wavelength or a channel for transmission is assigned. The optical network channels normally operate at 2.4 Gbits/s (OC-48) and above. If the source is 2 Mbit/s, the multiplexer should be in a position to groom these inputs to 2.4 Gbit/s. OADM adds and drops wavelengths to a band of wavelengths carried by an optical fiber. Complexity of grooming infrastructure is related to granularity of grooming. With current OADM, it is possible to extract wavelengths that terminate on a particular node instead of again demultiplexing and multiplexing all wavelengths carried by an optical fiber [14]. This reduces the cost of the OADM because the size of the OADM at each node is dimensioned to handle traffic that is dropped or added to a band of wavelengths [14].

Groomed traffic can use one wavelength from source to destination node. However, a wavelength can only be used by one traffic demand on a link. A wavelength which has been assigned to a demand at one node transverses a link on which this wavelength is used by another traffic demand, and a new wavelength must be assigned to avoid conflict. The assignment of a new wavelength to traffic on a OXC is known as wavelength conversion. OXC with wavelength conversion costs more than OXC without wavelength conversion.

B. Quality of Service (QoS)

Optical networks are high speed networks. When an optical cable is cut, data is lost at a terabit rate. Speed of restoration is one of the most important QoS parameters to be addressed in Service Level Agreements (SLA). We focus on QoS issues associated with each layer and how QoS affects the cost of DWDM resource provisioning. At the packet switching layer, QoS parameters include queuing delay, loss of packets, delay variation and throughput. At the OXC layer, QoS issues can be grouped into switching delay (sometimes, optical to electrical and back to optical conversion) and throughput. At the wavelength division multiplexing layer the QoS is the probability of blocking. Blocking at wavelength division multiplexing layer the QoS is defined in this paper as unavailability of a wavelength at one or more links used by the traffic demand. At the physical layer, the QoS issues are BER and restoration or protection time. We do not discuss the packet switching layer QoS because our resource allocation problem involves three bottom layers i.e., OXC layer, wavelength division multiplexing layer and physical (fiber) layer. Enough wavelengths are provided in wavelength division multiplexing for the offered demand. At the physical layer amplifiers are used to boost the strength of signals. In this way, BER is reduced. Lastly, OXC should have enough capacity to meet the demand.

Traffic demand is grouped into Classes of Service (CoS). If traffic in the same CoS is multiplexed and assigned a wavelength, this wavelength is treated based on QoS of the CoS. For example, restoration and protection is provided to CoS that does not tolerate interruption in traffic flow. Other CoSs are not provided with protection or restoration. This reduces the costs of equipment but provides protection based on SLA request for restoration and protection requirements.

V. RESOURCE ALLOCATION

For a given traffic demand in existing nodes, we have developed an algorithm to identify the working and restoration routes for each traffic demand. This step is followed by wavelength assignment and lastly the required equipment and associated costs are calculated. We provide steps to be followed in wavelength assignment and equipment cost minimisation. We use an existing network topology being used by legacy transport system as shown in Fig. 3 as our client layer. The network has five nodes numbered from 1 to 5. The nodes are connected by links numbered from x1 to x7 as shown in Fig. 3.

A node contains some or all of the following elements: digital cross connect, OXC unit, channels of WDM port
units, and ports of OXC. The links are composed of 1 or more pairs of fiber cables. Each fiber cable may contain tens of channels (each wavelength forms a channel). If the fiber cable is very long such that it can cause signal attenuation, the fiber cable may have optical amplifiers to boost the strength of signals [7][10][17].

A. Traffic Demand

Table I shows the demand to be transported from source node to destination node for the network of Fig. 3. The traffic demand is grouped into classes of service A, B and C, based on QoS requirements. It has been assumed that traffic is symmetrical on a source - destination (e.g., if the source has 10 OC-3 to transport to the destination node, then the destination node also has 10 OC-3 to be transported to the source node) pair. The values of traffic are in OC-3 units (STM-1).

<table>
<thead>
<tr>
<th>Source Node</th>
<th>Destination Node</th>
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<tbody>
<tr>
<td></td>
<td>CoS</td>
</tr>
<tr>
<td>1</td>
<td>A 6 1 2 5</td>
</tr>
<tr>
<td>1</td>
<td>B 5 2 10 8</td>
</tr>
<tr>
<td>2</td>
<td>C 7 9 8 1</td>
</tr>
<tr>
<td>2</td>
<td>A - 6 - 4 6</td>
</tr>
<tr>
<td>2</td>
<td>B 3 7 2 5</td>
</tr>
<tr>
<td>2</td>
<td>C 9 8 1 -</td>
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<tr>
<td>3</td>
<td>A 1 4 7 -</td>
</tr>
<tr>
<td>3</td>
<td>B 6 6 - 4 9</td>
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<tr>
<td>3</td>
<td>C 4 10 2 5</td>
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<tr>
<td>4</td>
<td>A 2 8 7 2</td>
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<td>4</td>
<td>B 5 6 8 6</td>
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<td>C 2 4 1 5</td>
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<tr>
<td>5</td>
<td>A 5 6 2 -</td>
</tr>
<tr>
<td>5</td>
<td>B 4 1 7 3</td>
</tr>
<tr>
<td>5</td>
<td>C 8 3 1 5</td>
</tr>
</tbody>
</table>

**TABLE I**

**NETWORK TRAFFIC DEMAND**

The demands shown in Table I traffic demand to be transported. The standard attainable sizes of optical channels range from 2.5 Gbits/s (OC-48) to about 10 Gbits/s (OC-192), and 40 Gbits/s (OC-768) in the future. Each fiber cable may contain multiple wavelengths, for example, 160 [18]. The cost of fiber cables is directly proportional to the number and size of channels the fibre accommodates. As the total bandwidth in a cable is constant, there is a trade off between number of channels and the size of channels. The size of the channel selected should be able to carry traffic demands of a given class of service from source to destination.

B. Algorithm

The Algorithm uses traffic demands at each node and network topology to calculate wavelengths and number of fibers required [16]. Once the number of optical channels and number of fibers are known, it is possible to calculate all other components needed to install an optical network system based on DWDM.

![Static Resource Allocation Algorithm](image)

**Fig. 4. Static Resource Allocation Algorithm [16]**

<table>
<thead>
<tr>
<th>Source Node</th>
<th>Destination Node</th>
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<tbody>
<tr>
<td></td>
<td>CoS</td>
</tr>
<tr>
<td>1</td>
<td>A 1 x1 x2 x3 x1</td>
</tr>
<tr>
<td>1</td>
<td>B 2 x2 x1 x3 x5</td>
</tr>
<tr>
<td>1</td>
<td>C 3 x1 x5 x1 x6</td>
</tr>
<tr>
<td>2</td>
<td>A 4 x3 x5 x4 x6</td>
</tr>
<tr>
<td>2</td>
<td>B 5 x3 x4 x7 x5</td>
</tr>
<tr>
<td>2</td>
<td>C 6 x5 x4 x3 x6</td>
</tr>
<tr>
<td>3</td>
<td>A 7 x6 x5 x3 x7</td>
</tr>
<tr>
<td>3</td>
<td>B 8 x4 x7 x5 x6</td>
</tr>
<tr>
<td>3</td>
<td>C 9 x4 x7 x6 x6</td>
</tr>
</tbody>
</table>

**TABLE II**

**ACTIVE AND PROTECTION PATHS**

C. Path Allocation

Table II shows assignment of paths to classes of traffic. W stands for working path while P stands for restoration or protection path. Traffic in classes A and B is assumed to require a very low restoration time (less than 50 ms) and a very lower BER. These requirements translate into provisioning restoration paths that deliver required QoS. The optical amplifiers are positioned at the right distances apart to boost signals and minimize attenuation, the fiber cable may have optical amplifiers to boost the strength of signals [7][10][17].
the BER. Wavelengths are assigned to the forward light path channels. These wavelengths are reused in the reverse direction light path because a pair of fiber cable is used (one cable carries traffic in the forward direction while the other cable carries traffic in the reverse direction). There are two approaches for wavelength assignment to light paths: Wavelength Path (WP) and Virtual Wavelength Path (VWP). WP assigns a wavelength to traffic that is used from source to destination node. It does not change in intermediate nodes. VWP uses wavelength converters to assign different wavelengths to traffic when the previous wavelength is in use at an intermediate node.

Information in Table II is read as follows. For example, traffic at the node with classes of Service A and B to destination node 5 use links X1 and X6 as the working path and links X2, X4, and X7 are used as the restoration path.

D. Cost Calculation

The actual provisioning problem of resources is an integer linear programming problem. It identifies components required to transport demands and minimize the total cost of equipment. The model of the system is presented below. In these definitions, “type” refers to capacity of the equipment being considered. The definitions of terms used in the calculations are appear in Table III.

\[
\text{cost of optical channels ports}\quad C_{\text{AMP}} = \sum_{i,j \in N} d_{ij} \cdot C_{\text{AMP}_{ij}}, \quad \forall j > i
\]

2) Calculating Costs:

1) Cost of WDM

This equation calculates the cost of OADM for each port (link) connected to node \(i\). If traffic is not being added or dropped, use WDM without OADM functionality.

\[
C_{\text{WDM}} = \sum_{i \in N} \sum_{k \in N} \sum_{x \in WDM} C_{\text{WDM}_{ikx}}, \forall i, k, t > k
\]

2) Cost of fiber cables The equation calculates the cost of all fiber used to interconnect nodes in the network.

\[
C_{\text{FIBRE}} = \sum_{i \in N} \sum_{k \in N} C_{\text{FIBRE}_{ikx}}, \quad \forall j > i
\]

3) Cost of OXCs

The OXCs are installed where switching is required. There are various types of OXCs supporting different functionality such as wavelength conversion, connection to digital cross connect (DXC), splitting capability, etc [16]. The cost is proportional to the cost of OXC features.

\[
C_{\text{OXC}} = \sum_{i \in N} C_{\text{OXC}_i}
\]

4) Cost of Channel of WDM Ports

Each channel has its own transmitter and receiver [3]. The cost of transmitters and receiver is calculated as follows:

\[
C_{\text{CH}} = \sum_{x \in S_{ik}} \sum_{y \in CH_{x} \in S_{ik}} C_{\text{CH}_{x,y} \in S_{ik}}, \forall S_{ik}, k > t
\]

5) Calculating Cost of Amplifiers

Amplifiers are used in optical transport system where the distance is so great that it causes attenuation of light signals. In some cases, more than one amplifier is used.

\[
C_{\text{AMP}} = \sum_{t, k \in N} d_{tk} \cdot C_{\text{AMP}_{tk}}, \quad \forall X_{tk}, k > t
\]

The objective function is obtained by adding costs in equations 2 to 6. The objective function minimises the total cost of components required to set up a DWDM core network backbone.
Minimise $C_{\text{WDM}} + C_{\text{Fibre}} + C_{\text{OXC}} + C_{\text{CH}} + C_{\text{AMP}}$

subject to:

$C_{\text{WDM}} > 0, \quad C_{\text{Fibre}} > 0, \quad C_{\text{CH}} > 0, \quad C_{\text{AMP}} > 0, \quad C_{\text{OXC}} > 0$

VI. CONCLUSIONS

The NGN architecture supports a multiservice environment with different QoS needs. An optimized DWDM backbone provides reliable transport mechanism for diverse services of the NGN. Like any other investment, the deployment of DWDM requires minimizing capital expenditure while supporting all traffic demands from client layer at a QoS specified in SLA.

DWDM provides enough bandwidth to support SDH, Frame Relay, IP, ATM etc. as client layers. Traffic from the client layer is groomed into higher bit rate to make optimum use of the optical network resources. In addition, grooming helps optical network providers to support required QoS by multiplexing traffic with similar QoS needs into the same Classes of Service (CoS) and providing restoration to wavelengths carrying traffic in CoS that requested restoration / protection in SLA.

Mesh topology is better for core network deployment than ring because it is scalable for large traffic and it is cheaper when used over long distances. Even though a ring network is suitable for metro and regional networks, it fails to meet the challenges created by an ever increasing demand and the long distance between nodes in the core network.

We have formulated a method for identifying the number of wavelengths and fibre cables required for migration from existing methods of transport systems to DWDM. We have also formulated a cost minimization solution of the cost of equipment required to route given traffic.

REFERENCES


Biography:
Tiwonge Kawonga is a postgraduate student at Wits University. His research interest is in area of optimization in the core network.

Hu Hanrahan is Professor of Communications Engineering at Wits University. He leads the Centre for Telecommunications Access and Services (CeTAS), a research and advanced teaching centre devoted to improving knowledge and practice in the evolving telecomms access networks and telecomms services.