OPTICAL NETWORK DESIGN WITH GEOGRAPHIC DISTRIBUTION INFORMATION

Wei Guo [a], Jing Guo [b], Yaohui Jin [a], Weiqiang Sun [a], Weisheng Hu [a]

[a] State Key Lab of Advanced Optical Communication System and Network,
Shanghai Jiao Tong University, P.R.China, 200030 -{wguo, jinyh, wqsun, wshu}@sjtu.edu.cn
[b] School of Power and Mechanical Engineer, Wuhan University, P.R.China, 430072 - ylguo@whu.edu.cn

KEY WORDS: Optical network, Network planning, Network design, Optimization, Geographic distribution, Traffic, Availability

ABSTRACT:

An accurate estimation of network performance is critical for the success of optical networks design. Traffic modeling and availability modeling for optical network are at heart of optical network design. Traffic models and availability models need to be accurate and able to capture the statistical characteristics of the actual traffic and the ability of a network to sustain failures. However, conventional traffic models are limited to characterize the traffic only in a single cell. Similarly, conventional availability models are limited to characterize the network availability only in a length of the link and the hardware equipment failure rate. They do not consider the spatial variation of the network availability within the urban or rural area. In this paper, a novel network traffic model and availability model based on the geographic information system (GIS) has been proposed. The approach can design accurate network traffic and availability models, not only the amount of a network node's add/drop traffic and the amount of the network component failure are regarding, but also their geographic distribution.

1. INTRODUCTION

Optical network introduction has been one of the most significant changes in the telecommunications industry in recent years. With the increasing deployment and growth in optical transport networks, solving the classic network design problem of optimizing cost and scalability becomes ever critical.

A basic optical network design process can be describes as following:

1. Collect input information – three types of input information must be collected at least, the information includes: node, traffic load, and network topology with current and future fiber types and routes.
2. Conduct design iteration – based on the provided information, network planner use various network design techniques and tools to create a network solution for the customer that meets a given set of requirements.
3. Outputs – the network solution outputs all information required for the network deployment, including the flow of the routed demand pairs, the link and node loads, and all the equipment needed to support these loads.

The fundamental designing objectives in an optical network concern the optimizations regarding the following two metrics: The first one is to minimize the network total cost. The second one is to maintain an acceptable quality of service (QoS), centered service level agreements (SLA), that is deliverable by the network.

An accurate estimation of network performance is critical for the success of optical networks design. So traffic modelling and availability modelling for optical network are at heart of optical network design. If the traffic models and availability model do not accurately represent actual traffic and reliability of network, one may overestimate or underestimate network performance. Therefore, traffic models and availability models need to be accurate and able to capture the statistical characteristics of the actual traffic and the ability of a network to sustain failures.

Traffic models can be classified in general into two classes: short-range and long-range dependent. Short-range dependent models have a correlation structure that is significant for relatively small lags. Long - range dependent traffic models have significant correlations even for large lags. A variety of traffic models have been proposed. However, these traffic models are limited to characterize the traffic only in a single cell and do not consider the spatial variation of the traffic within the service area. In fact, there exists a strong correlation between the add/drop traffic of a network node and its proximity to other network nodes. This is due to the tendency of people to populate metropolitan areas and conduct their economic activities in these metropolitan areas. For example, it is expected for metropolitan areas to contain more network nodes than rural areas, and for these network nodes to have more add/drop traffic than those in rural areas. The add/drop traffic of a network node as well as its proximity to other network nodes should thus be taken into account when designing optical network. In order to design accurate traffic models, not only the amount of a network node's add/drop traffic is important, but also its geographic distribution, such as regional population and economics.

In the same way, the optical network availability usually be defined as the probability that a component (optical fiber link, equipment, connection, etc.) will be found in the normal operating state at a random time in the future(Clouqueur et.al.,2002). Number of network availability models to quantitatively estimate a network's availability have been proposed (Chu et.al., 2002; Zhang et.al., 2003; Huang et al., 2004; Radio et.al., 2001; Kong et.al., 2004). However, these network availability models are limited to characterize the network availability only in a length of the link and the hardware equipment failure rate, and do not consider the spatial variation of the network availability within the urban or rural area. In fact, there exists a strong correlation between the network availability and its geographic distribution.

Equipments are located in different geographic area. Fibers are put into cables, which are buried into different ducts under the ground. It is expected that the equipments or cables lied in abominable geographic environment may get more failure than that in favourable geographic environment.

The major drawback of commonly used conventional models is that the spatial variations of the traffic and availability are either not addressed effectively or are considered only in a very late stage of the design process. The handling of this issue is usually left to the expertise of the network design engineer. In particular, the design of optical networks has to be based on the analysis of the distribution of the expected spatial traffic demand in the complete service area and the accurate statistical characteristics of the ability of a network to sustain failures.

In this paper, we will survey and examine traffic and availability models that are currently used in the literature and propose novel geographic network traffic and availability model based on the geographic information system (GIS). The offered traffic and availability in a region can be estimated by the geographical and demographical characteristics of the service area. Such a traffic model and availability model relates factors such as regional population density, vehicular traffic, income per capita, cables' qualities and geographic environment. The information can be used in traffic model to estimate the traffic relationship between all network nodes from which the estimated add/drop traffic of all network nodes can be calculated, it also can be used in availability model to estimate the ability of a network to sustain failures more accurately. The approach would overcome the disadvantage of commonly used conventional models by regarding the spatial traffic demand distribution and network availability in the service area as a major input factor among the design constraints.

2. TRAFFIC MODEL

Traffic models can be stationary or nonstationary. Stationary traffic models can be classified in general into two classes: short-range and long-range dependent. Short-range dependent models include Markov processes and Regression models. These traffic models have a correlation structure that is signif-icant for relatively small lags. Long- range dependent traffic models such as Fractional Autoregressive Integrated Moving Average (F-ARIMA) and Fractional Brownian motion have significant correlations even for large lags.

Specifically, the stationary traffic model can be described by a suitable traffic matrix, whose generic element $\overline{b_{ij}}$ is a vector of lightpath between node i and node j.

$$[T]=\begin{bmatrix} \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \overline{b_{ij}} & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{bmatrix} \qquad \overline{b_{ij}}=\begin{bmatrix} b_{ij}^{(1)} \\ b_{ij}^{(2)} \\ \cdots \\ b_{ij}^{(N)} \end{bmatrix} \tag{1}$$

With $b_{\min} \le b_{ij}^{(n)} \le b_{\max}$, where $b_{\min}$ and $b_{\max}$ are the minimum and maximum possible bandwidth of an lightpath, respectively.

The value b_{ij} is defined as traffic load. A traffic load can be thought as a current or projected demand that the network must accommodate. Traffic loads come in two varieties: DCL loads, which represent SONET/SDH demands, and OCH loads, which represent optical-channel demands. Most network-design operations (routing, dimensioning, and so on) take a traffic load and derive the most optimal network configuration to support that load.

Once a baseline topology has been created, the next step is to create one or more traffic loads. A traffic load is the values that specify the level of traffic between each node in the topology. The traffic model views the load as a "traffic demand forecast" and configures the network to meet this forecast. The following steps outline the general workflow when creating a traffic load:

1. Create the baseline topology, with all nodes and links to populate with traffic.
2. Select the layer (OCH or DCL) of the traffic load you want to create. OCH and DCL loads represent different traffic demands at different layers: SONET/SDH traffic demands at the DCL layer vs. optical-wavelength demands at the OCH layer.
3. Specify the Bit rate, such as STM-1, STM-4, STM-16, STM-64, for the load. Select the traffic arrival processes, which are described by different traffic model.
4. The Selected Matrix table fills with integer values. These values specify the number of bidirectional wavelength demands (OCH layer) or bidirectional time slots (DCL layer) at the specified bit rate.

A number of traffic models have been shown to capture certain aspects of the statistical properties of measured data traffic.

1. Random : to specify varying traffic levels between nodes;
2. Uniform : to specify a uniform traffic level for every pair of nodes;
3. Poisson Process: The Poisson process has negative exponentially distributed interarrival times (r.v.T) with distribution function:

$$F(t)=1-e^{-\lambda t} \tag{2}$$

and its only parameter *h* is determined by

$$\lambda=\frac{1}{E[T]} \tag{3}$$

4. Markov Modulated Poisson Process: The Markoi Modulated Poisson Process (MMPP) is a versatile class of traffic models. However, difficulty arises when using the model to fit real data as the state space increases. The 2-state MMPP has 4 parameters $\lambda 1, \lambda 2, \mu 1$, $\mu 2$, where $\lambda 1$ and $\lambda 2$ are the conditional arrival rates, and $\mu 1$ and $\mu 2$ are the conditional

transition rates given that the Markov chain is in state 1 and 2 respectively. The time interval Δt we use to match the arrival rates is 10 msec. The mean m1, variance m2, 3rd moment m3, and the lag-1 autocorrelation coefficient c1 of the number of arrivals in 10 msec intervals are used to match the trace and the 2-slate MMPP as follows:

$$\begin{aligned}
\lambda_1 &= m_1 + \sqrt{\frac{m_2}{\eta}} \\
\lambda_2 &= m_1 - \sqrt{m_2 \eta} \\
\mu_1 &= \frac{1}{\tau(1+\eta)} \\
\mu_2 &= \frac{\eta}{\tau(1+\eta)} \\
with\ \eta &= 1 + \frac{\delta}{2}[\delta - \sqrt{4+\delta^2}\,] \\
\delta &= \frac{m_3}{\sqrt{m_2^3}} \\
\tau &= \frac{\Delta t}{\ln c_1}
\end{aligned} \tag{4}$$

3. AVAILABILITY MODEL

Most availability models assume constant failure rate (λ) and repair rates (μ). Availability A of some system/network in the time frame is defined as a ratio of time during which the system/network is functional in relation to the total operational time (Clouqueur et.al.,2002), i.e. it's probable that the system/network is functional in some time frame.

$$A = MTTF/(\ MTTF+MTTR) \tag{5}$$

where MTTF (Mean Time To Failure) is mean time till the failure occurs and MTTR (Mean Time To Repair) mean time of repair.

$$MTTF = 1/\lambda \tag{6}$$

$$MTTR = 1/\mu \tag{7}$$

λ is is usually expressed in FIT (Fai1ure in Time, 1 FIT=1 failure in l09 hours (~114 to 115 years)).

Unavailability U is probability complementary to availability, i.e. U=1-A. In reporting about system/network performances, unavailability U is often expressed as MDT (Mean Down Time) in minutes per year, i.e. MDT=3656024U [min/year].

For serial structure which includes n elements, the failure on any element causes unavailability of the whole structure. Availability of this structure is equal to product of individual elements, i.e.

$$A_s = A_1 A_2 \ldots A_n = \prod_{i=1}^{n} A_i \tag{8}$$

Generally, for parallel structure of *n* branches, availability is

$$A_p = 1 - \prod_{i=1}^{n} (1 - A_i) \tag{9}$$

For example, In Fig. 1, a line, Link_1, is available if the cable is available and if all OAs and Regenerators along the cable are available. In addition, the availability of the transponders, part of the line system and located at each side of the link in the opaque network scenario, is taken into account. Hence, the availability of Link_1 is given by:

$$\begin{aligned}
A_{Link\_1} = {} & A_{Cable\_Link\_1} * A_{OA}^{number\_of\_OAs} \\
& * A_{Regs}^{number\_of\_Regs} * A_{Transponder}^{2}
\end{aligned} \tag{10}$$

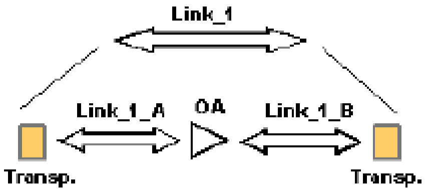


Figure 1. Line Availability

Another example can be shown in Fig.2. The connection AB is available if the working or protection path of the connection AB is available. Hence, the availability of connection AB is given by:

$$\begin{aligned}
A_{connection\_AB} = {} & A_{node\_A} \\
& * (1 - (1 - A_{working\_AB})(1 - A_{protection\_AB})) \\
& * A_{node\_B}
\end{aligned} \tag{11}$$

$$\begin{aligned}
where\ A_{working\_AB} &= A_{Link\_1} \\
A_{protection\_AB} &= A_{Link\_3} * A_{node\_c} * A_{Link\_2}
\end{aligned}$$

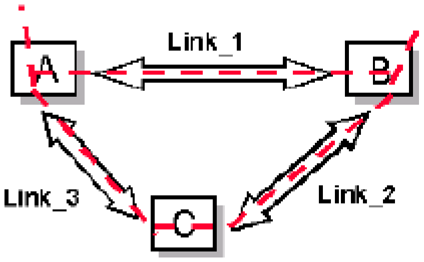


Figure 2. Connection Availability

4. GEOGRAPHIC TRAFFIC MODEL

In the geographic network traffic model, the requested traffic $A^{(n)}_{geo(ij)}(x,y)$ is the aggregation of the traffic originating from these various factors

$$A^{(n)}_{geo(ij)}(x,y) = \sum_{all\ factors\ k} a_k * \delta^{(n)}_k(x,y) \qquad (12)$$

where $\alpha_k = \lambda_k * E[B_k]$ is the traffic generated by factor *k* in an arbitrary area element of unit size measured in Erlangs per area unit, λ_k the number of call attempts per time unit and space unit initiated by factor *k*, *E[B_k]* is the mean call duration of calls of type *k*, and $\delta^{(n)}_k(x,y)$ is the assertion operator

$$\delta^{(n)}_k(x,y) = \begin{cases} 0 & traffic\ factors\ i\ is\ not\ true\ at\ location(x,y) \\ 1 & traffic\ factors\ i\ is\ true\ at\ location(x,y) \end{cases} \qquad (13)$$

Based on the above estimation method, the traffic characterization has to compute the spatial traffic intensity and its discrete demand node representation from realistic data taken from available data bases. In order to handle this type of data, the complete characterization process comprises four sequential steps.

Step 1) *Traffic model definition*: Identification of traffic factors and determination of the traffic parameters in the geographical traffic model.

Step 2) *Data preprocessing*: Preprocessing of the information in the geographical and demographical data base.

Step 3) *Traffic estimation*: Calculation of the spatial traffic intensity matrix of the service region.

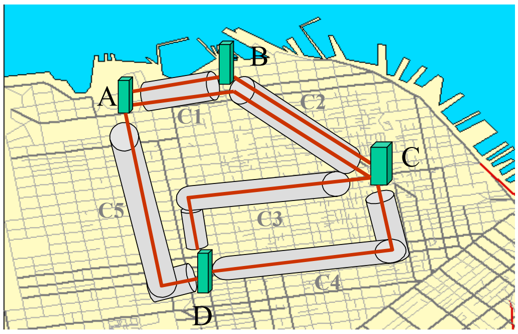
Step 4) *Demand node generation*: Generation of the discrete demand node distribution by the application of clustering methods.

To prove the capability of the demand estimation and to show the feasibility of the integrated and systematic design concept, a prototype of a planning tool for optical networks, will be implemented.

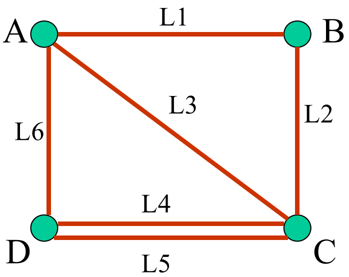
5. GEOGRAPHIC AVAILABILITY MODEL

As an example, a network with four nodes, five ducts, and six fibers is shown in Fig. 3(a). The logical topology is shown in Fig. 3(b). Link *L4* and *L5* have the same length. They are buried into different ducts *C3* and *C4* respectively. For connection *r* from node A to node B, we might get two fiber-disjoint paths purely on the logical topology. The primary path is *(A, L1, B)*, and the backup path is *(A, L3, C, L4, B)*. If we do not take into consideration the geographic distribution, we can compute the availability of link L4, L5 and connection *r* based on the above availability model. A link availability is only consists of its length. It is reported as per/km quantities. So we can get that $A_{L_4} = A_{L_5}$ and $A_{L_1}, A_{L_2}, A_{L_3}$ are irrelative.

However, note that duct C3, C4 are buried in the different geographic environment, link *L4* and *L5* going through C3 and C4 will possess different availability. In the same way, link L3 and L1 are going through the same duct C1 and link L3 and L2 are going through the same duct C2. Hence, the availability of link L3, L1 and L2 are interdependent.



(a) network and geographic distribution



(b) Logical topology

Figure 3. Example network

In the geographic network availability model, the availability of a duct can be denoted as:

$$A_{duct} = \sum_{all\ factors\ k} (c_k * g_k) \qquad (14)$$

where g_k is the availability generated by factor *k* in the area where the duct *j* located in. $0 \le g_k \le 1$. The factor *k* include temperature, humidity, insect pests, quality of ducts, land use, vehicular traffic, degree of pollute, etc. g_k can be calculated by GIS spatial analysis algorithm. c_k is the constant number, $0 \le c_k \le 1$ and $\sum_k c_k = 1$.

An optical network generally consists of network components such as links, nodes and connections. A link is available if the duct and cable are available and if all OAs and Regenerators along the cable are available. In addition, the availability of the transponders, located at each side of the link in the opaque network scenario, is taken into account. Hence, the availability of link is given by:

$$A_{link} = A_{duct} * A_{Cable} * A_{OA}^{(num\_of\_OA)} * A_{\mathrm{Regenrator}}^{(num\_of\_\mathrm{Regenrator})} * A_{Transponder}^{2} \quad (15)$$

The node availability depends on components (units) from which the node consists, such as geographic location, subrack, optical units, multiplex units, switching unit and units for transport signals being added and dropped at the node, Total availability is equal to the product of availabilities of single units, i.e.

$$A_{node} = A_{geo\_location} * A_{subrack} * A_{optical\_U} * A_{multiplex\_U} * A_{switching\_U} * A_{add/drop\_U} \quad (16)$$

Connection *i* is available only when all the network components along its route are available. Let A_j denote the availability of network component *j*. Let S_i denote the set of network components used by connection *i*. Then the availability of connection can be computed as follows:

$$A_i = \prod_{j \in S_i} A_j \quad (17)$$

The 1+1 protected connection *c* is available if the primary path *p* or backup path *b* of the connection is available. Hence, the availability is given by:

$$A_c = 1 - (1 - A_p)(1 - A_b) \quad (18)$$

For connection from node A to node B in Fig.1, there are three different connection routes, unprotected connection *r1: (A, L1,B),* 1+1 protected connection *r2: {p(A, L1,B),b(A,L3,C,L2,B)}* and *r3: { p(A, L1,B), b(A,L6,D,L5,C,L2,B)}*, We can compute the availability of these connections under different availability for duct C1, where we set other components availability is equal to 0.998. From result shown in Table 1, we can see that a desired backup path of a given connection should not share any duct with the primary path of the same connection. Geographic network availability model is more accurate to describe the network availability.

connection	α_{duct_c1}=0.998	α_{duct_c1}=0.8	α_{duct_c1}=0
r1	*0.99418*	*0.7968032*	*0*
r2	*0.9959937*	*0.9555546*	*0*
r3	*0.9959868*	*0.9941228*	*0.986598*

Table 1. Availability of connection *r1, r2* and *r3*

6. CONCLUSION

This paper propose a novel geographic network traffic and availability model based on the geographic information system (GIS). The approach can design accurate network traffic and availability models, not only the amount of a network node's add/drop traffic and the amount of a network component failure are regarding, but also their geographic distribution. They would overcome drawback of commonly used conventional models that the spatial variations of the network component are either not addressed effectively or are considered only in a very late stage of the design process.

REFERENCES

ATM Forum, "ATM user-network interface specification," version 3.1, *ATM Forum document,* 1994.

Chu K. C., Mezhoudi M., and Hu Y., "Comprehensive end-to-end reliability assessment of optical network transports," *Proc., OFC'2002*, pp.228-230, March 2002.

Clouqueur M. and Grover W. D., "Availability analysis of span restorable mesh networks," *IEEE J. on Selected Areas in Communications*, vol. 20, issue 4, pp. 810-821, May 2002.

Cruz R., "A calculus for network delay, part I: Network elements in isolation," *IEEE Transactions on Information Theory,* vol. 37, Issue 1, pp. 114-121, January 1991.

Ferrari D., and verma D., "A scheme for real-time channel establishment in wide-area networks," *IEEE Journal on Selected Areas in Communications,* vol. 8, Issue 3, pp. 368-379, April 1990.

Huang et al. Y., "A generalized protection framework using a new link-state availability model for reliable optical networks". J. Lghtware Technol., vol. 22, no. 11, pp. 2536-2547, Nov. 2004.

Knightly E. W. and Zhang H., "D-BIND: an accurate traffic model for providing QoS guarantees to VBR traffic," *IEEE ACM Transactions on Networking,* vol. 5, Issue 2, pp. 219-231, April 1997.

Kong R. and Zhou H., "End-to-End availability analysis of physical network", IEEE 2004, pp. 1401-1405.

Lie Qian, et al. "A New Traffic Model and Statistical Admission Control Algorithm for Providing QoS Guarantees to On-Line Traffic", IEEE Globecom 2004.

Radio, Turalija P. and Sunaric T., "Availability Model of Bidirectional line switched ring". IEEE ICTON 2001.

Wrege D. E., Knightly E. W., Zhang H., and Liebeherr J., "Deterministic delay bounds for VBR video in packet –switching networks: Fundamental limits and practical tradeoffs," *IEEE/ACM Transactions on Networking*, vol. 4, Issue 3, pp. 352-362, 1996.

Zhang J., Zhu K., Zang H., and Mukherjee B., "A new provisioning framework to provide availability-guaranteed service in WDM mesh networks". *Proc. IEEE ICC*, May 2003.

ACKNOWLEDGEMENTS

The work described in this paper was supported by the NSFC and 863 program.