Traffic Modeling for Agile All-Photonic Network Dimensioning

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Abstract—**In the design of an Agile All-Photonic Network (AAPN), in order to determine the capacity and processing ability of links and interfaces, models of the source traffic volume, composition and distribution are necessary. In this paper, service specific bandwidth requirements for a putative set of services have been developed. Demographic information for three classes of users, namely residential, business and mobile, is input to the Topological Design Tool (TDT) and then passed to the MATLAB dimensioning routines. Stochastic process models for the various voice, data and video services supported are identified. With the effective bandwidth functions and the many sources asymptotic, the results give the capacity requirements needed to assure the target QoS levels.**

I. Introduction

The Agile All-Photonic Network (AAPN) is a fast optical switched network designed to support future services including multimedia communication systems [1]. Website www.aapn.mcgill.ca and [1] gives thorough description on the design of an AAPN. An AAPN is designed to provide a near cost-optimum logical network topology for integrated services with different characteristics such as QoS requirements, traffic attributes, and traffic demand. It is straightforward that the traffic demand distributions will influence not only the resulting network topology and the total cost, but also the efficiency and simplicity of the topology.

Our previous work has addressed the problem of topological design methods [1-3], where a gravity model for traffic distribution and a flat community of interest factor are used. In gravity model, traffic between sites is proportional to traffic originated at each site. There is no systematic difference between traffic in one node and another, and only the total volume matters. This flat model of Internet was selected initially for its simplicity. However, it is not service-oriented and not accurate enough. Thus better traffic models for various services types are considered for the "services of the future".

A lot of studies have been done on capturing the relevant statistical modeling properties of today's voice, data and video traffic. [4-7] gave a detailed review of current models for traffic streams. According to [8], the total projected traffic can be aggregated into several categories. Table I gives the traffic characteristics of these services. With the traffic volume of the different services as input, our objective is to determine the total capacity required for each link and interface.

The rest of the paper is organized as follows. Section 2 provides a brief introduction of TDT and the procedure for dimensioning the network with effective bandwidth formulae. Section 3 presents the computational results based on our solution procedure. Section 4 concludes.

TABLE I
Traffic Characteristics

Traffic types	Service types	Quality requirements	Characteristics
Real time traffic	VoIP, video conferencing, collaborative services	Low delay, low jitter, moderate loss	CBR
Interactive traffic	Near web, voice web: HSIA, XML, RSS, Webcam	Low loss, low delay	Rt-VBR
	here web: Mobile streaming, Location Awareness, IM	Moderate delay, low loss	
	Far web: HSIA via TV	N/A	
	e-Commerce	N/A	
	device web	Negligible	
Games	Near web	Moderate loss, moderate delay	Rt-VBR
	Here web, Far web: Interactive games	Low loss, low delay	
Data/NFS	Email, download, file transfer, update	No loss, insensitive to delay and jitter	Best effort, self-similar
Streaming	Near web, Far web: VoD, remote education, etc	No jitter, low loss, moderate delay	nrt-VBR
P2P	file sharing in MP3, DVD etc	No loss, insensitive to delay and jitter	self-similar
IP-VPN	Mix of voice, video, traffic	Low delay, low jitter, moderate loss	self-similar

II. Traffic Modeling in an AAPN

First we will give a quick review of our previous work in AAPN topological design. The objective is to design and dimension an all-photonic network to support the data transmission among end users. Various optimization methods are employed to determine the best configuration of the network facilities while minimizing the overall costs. We have developed a set of modular software tools and methodologies for design and visualization in MATLAB and Java, which is called TDT. Reference [1] and [2] introduces our TDT model for the case of uniform traffic demand.

This paper enhances the capability of the existing TDT. Traffic demands originating from different users with different service categories can be obtained as a TDT input. The dimensioning is performed with the following procedure:

Step 1: Map source traffic types to stochastic processes. Based on their specific transmission characteristics, different service types are mapped into proper processes accordingly.

Step 2: Effective bandwidth calculation for different traffic models. These can be obtained from Kelly's formulae [9] of effective bandwidth of different service types. Using the Many Sources Asymptotic rate function [10], the appropriate time and space parameters can be obtained.

Step 3: For the QoS requirement specified, the effective capacity of the system can be calculated, and the required capacity of each source will be determined.

Thus traffic demand from each node for each class of users can be calculated, resulting in a more precise point-to-point traffic demand matrix. With this result, the number and properties of the various interfaces on the edge nodes can be allocated. The following figure shows the working procedure of this method as implemented in the TDT.

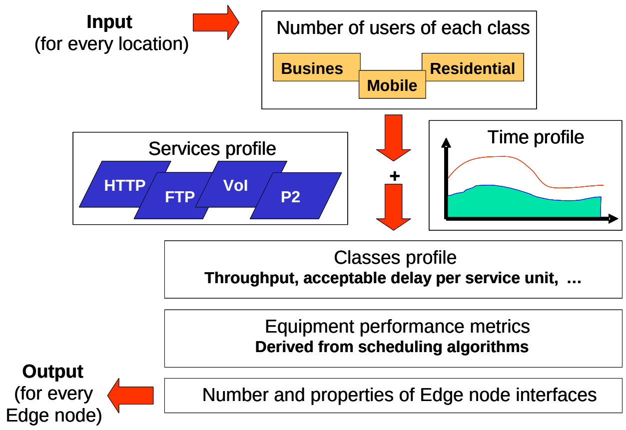

FIG. 2. WORKING PROCEDURE OF NETWORK DIMENSIONING

The program input is the traffic demand from one location. This is given by the number of three types of users: business: D_B , residential: D_R and mobile: D_M . The program output is the effective capacity from one location C^* .

A. Traffic models and effective bandwidth

A.1 Active number of users

As we don't model the process at the session level, we model the peak number of active users as a percentage of the total number of users. For example, for business type, active business user number $N_B = P_{active} \cdot D_B$.

Parameter P_{active} is a constant, and $P_{active} \in [0,1]$.

A.2 Traffic models and effective bandwidth

According to analysis in Table I, the traffic is modeled and the effective bandwidth will be calculated. Please note that in TDT, users are free to apply any proper model to the proposed traffic source regarding their actual network applications. Below we will give an example of the mapping. Because of the space limitation of the paper, the parameter settings in various models are not included and can be found in the references listed below.

Real – time traffic:

This kind of traffic can be characterized by strict bounds on delay and jitter; however, performance is not very sensitive to packet loss. This includes several traffic types such as VoIP, video conferencing and collaborative services. This traffic requires low delay, low jitter and moderate loss. According to these requirements, an On-Off model is selected as its traffic model. Then the effective bandwidth can be calculated with the following formula in [9]:

$$\alpha(s,t) = \frac{1}{st}\log\left[1 + p\left(\exp\left(st\alpha_1(s,t)\right) - 1\right)\right] \quad (1)$$

Following [10, 11], we set the real-time traffic (especially VoIP) parameters as follows:

On time=352ms, Off time=650ms, traffic rate: 64kbps

Interactive traffic:

This includes XML, RSS, Webcam, location awareness, IM etc. The traffic can be characterized by stringent bounds on packet loss but flexible delay and jitter constraints. The On/Off source model with heavy tail in the On time is used for this traffic. The parameters used are from [12]:

On time: 20s, Off time: 40s, traffic rate: 36kbps.

Game traffic:

Game traffic is also sensitive to loss and delay, and is modeled as heavy-tailed On-Off model. The parameters are from [13]: On time: 1s, Off time: 9s, traffic rate: 100kbps.

Data/NFS:

Burstiness and self-similarity are observed in the traffic of Data/NFS. It can be modeled as FBM and the effective bandwidth is given by [9]:

$$\alpha(s,t) = \lambda + \frac{\sigma^2 s}{2} t^{2H-1} \quad (2)$$

The parameters used are as follows in [14]:

Mean traffic rate: 0.5Mbps, variance: 1, Hurst H: 0.9

Streaming:

According to the nature of streaming services, especially TV programs, streaming traffic is bursty. There are also strong correlations in successive packet sizes. The traffic can be modeled by an MMPP. The effective bandwidth is [9, 15]:

$$\alpha(s,t) = \frac{1}{st}\log\left\{\pi \exp\left[\left(Q + (e^s - 1)\Lambda\right)t\right]1\right\} \quad (3)$$

The parameters are given by [16]:

The arrival rate in each state is $\Lambda = diag(\lambda_1 ... \lambda_m)$ =diag(0.116 0.274 0.931), the irreducible transition rate matrix is Q=(-0.12594 0.12594 0; 0.25 -2.22 1.97;0 2 –2), and the stationary distribution π has the following characteristics: $\pi Q = 0$, and $sum(\pi) = 1$.

P2P traffic:

P2P traffic is modeled as an On/Off model. The parameters are: On time: 20s, Off time: 5s, traffic rate: 250kbps.

IP-VPN traffic:

The traffic in VPN is mixture of data, voice and video. It is also self-similar and can be modeled as a FBM processes. The parameters are: Mean traffic rate: 0.2Mbps, variance: 1.5, Hurst parameter H: 0.9.

B. Effective bandwidth calculation

B.1 Buffer and capacity

The link has a shared buffer of size $B = N_B \cdot b$, where *B* is measured in milliseconds (ms). According to the delay tolerance of the services, *B* is normally in the range 1 to 50 ms.

The total link capacity is $C = N_B \cdot c$, measured in Mbps. *c* is the capacity per source. In our scenario, we specify *c*=1 Mbps.

B.2 Effective bandwidth and operation point

The effective bandwidth of each source node is calculated for different service types, then the sup-inf formula in [10]:

$$\sup_t \inf_s J(s,t) = \sup_t \inf_s \left[s \cdot t \cdot \sum_{j=1}^{J} n_j \alpha_j(s,t) - s(b + c \cdot t) \right] \quad (4)$$

can be solved.

This optimization is done by enumeration. An interval of $[s_a, s_b]$ and another interval of $[t_a, t_b]$ are chosen. With the values of s and t selected from the intervals, the value of $J(s,t)$ can be calculated. The result of the sup-inf formula is found by $\max_t \min_s J(s,t)$, which is denoted as (s^*, t^*).

B.3 Effective capacity

As shown in [10], with a given probability of overflow $P(overflow) \le e^{-\gamma}$, the effective capacity is:

$$C^* = C + \frac{1}{t^*}\left(B - \frac{\gamma}{s^*}\right) \tag{5}$$

The Bahadur-Rao capacity is:

$$C^* = C + \frac{1}{t^*}\left(B - \frac{\gamma'}{s^*}\right) \text{ where } \gamma' = \gamma - \frac{(1/2)\log(4\pi\gamma)}{1+(1/2\gamma)} \tag{6}$$

C. *Traffic matrix and network design*

For each edge node in the network, the same procedure of calculating the effective bandwidth is repeated. After we get the source traffic demand, the traffic matrix is generated with the gravity model. Using this result, the allocation and connectivity of selector switches and core nodes can be designed as shown in [1-3].

III. Data Analysis

According to [10], the results of effective capacity against buffer size with four different values of overflow probabilities are given in the following figure:

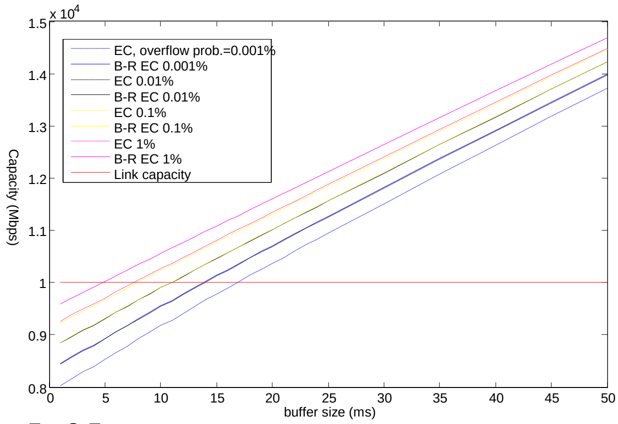

Fig. 3. Effective capacity with different overflow probabilities

Clearly in Fig. 3, the effective capacity increases as the buffer size increases. When the overflow probability is fixed, the more accurate Bahadur-Rao improvement achieves better performance than that of the many sources asymptotic

TDT can support the complex demand models in network design. TDT users can set proper demand parameters, specify the traffic models, or modify service inputs based on current or future traffic requirements. In each location, the number of Residential, Business and Mobile customers (population) can be specified. For each customer's each service, different traffic models can be chosen by the TDT users according to their own traffic characters. All these traffic parameters have been considered in the network design procedure.

Examples of a 2-layer network design produced by TDT are shown in Fig. 4. These diagrams are results of optimization procedures executed by TDT based on algorithms discussed above. For a given set of node geographical locations, their cable connections, plus different traffic demands, the optimal core node placement and logical interconnection topology is produced. The left figure shows the network topology where all the locations have the same traffic demands. The right one gives the topology where location 1 and 2 has tripled traffic demands than those in the left.

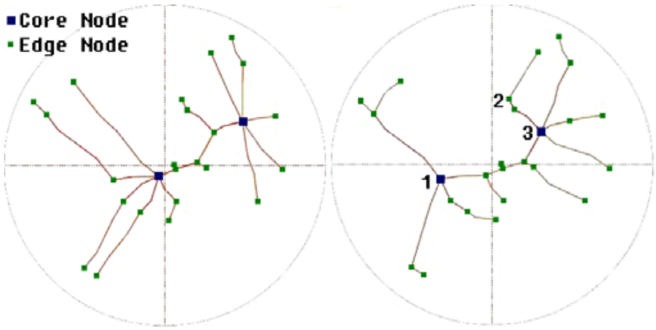

Fig. 4. Network design with different traffic demand

IV. Conclusion

We give the procedure of accurate dimensioning in network design. Each service class can be studied separately with specific traffic models, which can be used for service specific applications like service tariffs etc. The quantity and distribution of different traffic source classes (business, residence, mobile) are also included. The theory of effective bandwidth and many sources asymptotic have been used to calculate the traffic. The network design results are also given. This approach to traffic engineering in the AAPN enhances the capability of the existing Topological Design Tool.

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