Traffic Trends: Drivers and Measures of Cost-Effective and Energy-Efficient Technologies and Architectures for Backbone Optical Networks

Steven K. Korotky
Alcatel-Lucent, Bell Laboratories, Crawford Hill Laboratory, Holmdel, NJ, USA
steven.korotky@alcatel-lucent.com

Alternate: We examine trends and characteristics of the traffic, systems, and architectures of backbone optical networks to illustrate baselines, future requirements, and possible metrics to gauge the relative performance of capabilities and concepts being researched today.
OCIS codes: (060.0060) Fiber Optics and Optical Communications; (060.4250) Networks

1. Introduction

While technologies and applications can be revolutionary, the communication networks that use and support them tend to be evolutionary. Arguably, this is because the complexity, cost, and criticality of a communication infrastructure far exceed those of any individual new component or use. And too, commensurate with the predictions of future technologies and applications that could bring radical change is uncertainty. Consequently, access, regional, national and global backbone networks are usually built-out and replaced gradually for reasons of affordability, backward compatibility, and deployment flexibility. Conversely, to remain viable, the inherent inertia of large networks suggests it is imperative that potential changes in the requirements, technological choices, and architectural options are considered and understood well in advance of decisions and actions. Roadmapping of requirements and technologies is intended to frame plausible reference scenarios in the face of the unknowns.

Naturally, the expected traffic is a basic requirement imposed on network design. However, the traffic flowing across a general, multi-purpose communication network, such as an optical backbone, is not an immutable quantity. It is rarely constant in time or uniform over space. Rather, traffic is one of many interdependent variables of a network and is the result of the complex interactions among them. Variables that influence network traffic include the details of users' applications and behaviors, transport costs, resource constraints, pricing strategies, network element and network architectures and capabilities, and their temporal and geographic variations – to name but a few. However, because of the scale of the backbone of a large network, we also consider that underlying systematic dependencies may be reinforced and can result in significant trends or appear as correlations between variables. The effect of changes in the variables upon each other is often explored by perturbative and iterative methods. Consequently, network traffic data can be considered both a driver (input) and measure (output) of technological productivity and network performance.

For the above reasons it is useful to examine the recent and historical trends and characteristics of the traffic, systems, and architectures of backbone optical networks and to look for general behaviors that may be indicative of more fundamental dependencies – ones that are sustained and expressed independently of the details of particular instances of networks. Specifically, in this paper we review a sampling of recent reports, analyses, and models on the subject of macro-characteristics of backbone network traffic that may be useful to roadmap the dimensions and features of future network elements and to compare candidate network solutions on the basis of cost-effectiveness and energy-efficiency.

2. Long-term Traffic Trends

As part of an initiative to investigate energy consumption and improve the energy efficiency of communication networks, we have recently analyzed historical reports of data traffic carried by public backbone networks using regression methods, and have projected the traffic volumes forward [1]. One component of our study, which was carried out independently of other recent surveys and forecasts, focused on the compound annual growth rate (CAGR) of data traffic over public backbone networks and the corresponding traffic volume for North America [2,3]. We have found that the projection of the curve fitted to the compound annual growth rate of overall IP traffic and the corresponding forecast of Ref. [2] (global IP) fall within the 95 % confidence interval of the former. For this review, we have produced a composite projection by carrying out a regression analysis of the data set consisting of the historical growth rates for public data traffic cited in Ref. [1] combined with the forecast of Ref. [2]. [Note, now the public data transport networks are commonly referred to simply as IP backbone networks because of the predominance of the use of the Internet Protocol.]

Shown in Fig. 1, where the CAGR is plotted versus year, are the input data from the several sources (see Ref.'s [1,2]) and the fitted curve of the regression. If the source dataset with the largest empirical variation is omitted from the regression, the present rate of growth of traffic on the global IP backbone is estimated to be 38% (corresponding to a doubling in approximately 26 months) with a statistical 95% confidence interval of 33-44%. These growth rates are comparable to the value reported for the sample network in Ref. [3]. The various data illustrated in Fig. 1 also indicate that the growth rate of traffic on the global IP backbones has generally been decreasing, including during the period of explosive growth (CAGR > 100%) prior to voice traffic exceeding data traffic (c. 2001). Thus, strictly speaking these traffic data are described by sub-exponential growth. The projected CAGR and confidence interval in 2022 are 24% (corresponding to a doubling in 38 months) and 20-29%, respectively. Based on the present regression analysis of the composite dataset, we would expect global backbone traffic, and therefore required capacity, to increase by approximately a factor of ~12X over the next decade. Regarding absolute traffic volumes, as one example, last year it was reported that a large carrier's network serviced 23.7 PB / business day [4].

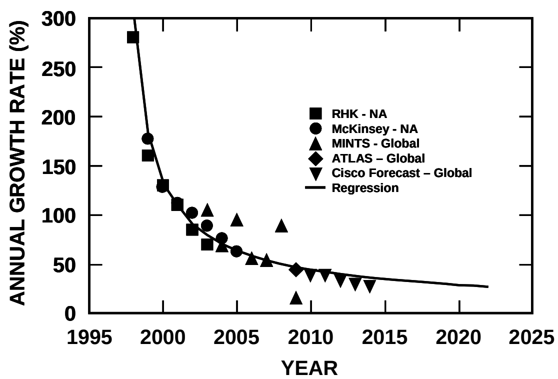

Fig. 1 Global IP Traffic Growth Rate

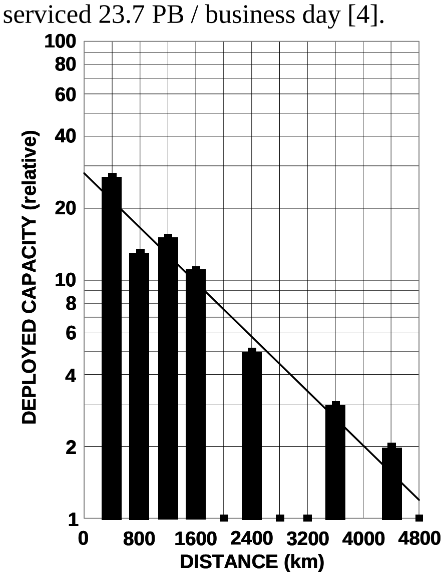

Fig. 2 Spatial Distribution of Deployed Capacity

3. Medium-term Traffic Variations

The characteristics of backbone network traffic on short- and medium-term scales is of interest for a variety of reasons including the assessment of peak traffic loads for capacity dimensioning and the identification of periods of low traffic load for energy-savings opportunities. In a recent study, wavelet analysis of packet traffic on the core of an IP backbone network was used to identify the dominant contributions at time-scales longer than 1 hour [5]. The authors found that a two component model consisting of a long-term trend and variations at shorter time scales associated with diurnal and weekly cycles accounts for 98% of the spectral content of the time dependence of the measured traffic. The ratio of maximum to minimum traffic during daily cycles has been observed to be as large as 2-2.5X between individual node pairs as well as for continental totals [5,6].

4. Distance-Dependence of Capacity Deployment

Statistically, voice traffic volumes were known to decrease with increasing distance between locations, which is perhaps expected when toll rates differentiated between local and long distance calls [7]. As the cost of the transport network is only a portion of the total cost to provide Internet service, and the rates consumers are charged for Internet service are not based on distance, it has been considered that the integrated traffic volumes between nodes of backbone IP networks might be relatively uniform [7]. However, in contrast to flat service rates, the cost to deploy capacity between pairs of nodes (for example in the form of wavelengths over optical fiber) is most certainly a function of the distance between nodes. And this strong underlying correlation between the cost of transport capacity and distance may emerge in the collective traffic pattern either directly or indirectly, such as through stigmergic behavior. For example, there is incentive for network operators and content providers to implement techniques, such as distributed caching, to avoid repeatedly transporting over long distances identical copies of large volumes of data of interest to many users. Also, users may benefit from the reduced latency of more local interactions.

To investigate the distance-dependencies in IP backbone networks, we have recently analyzed the capacity deployments that have been publicized for a large IP backbone network [8]. In Fig. 2 we plot the histogram of deployed capacity versus the highway route distance between the nodes that is obtained for 400-km wide bins. The diameter (largest of the minimum path length distances) of the network is 4400 km, and we observe that the envelope of the density function can be approximated by an exponential dependence with a 1/*e* distance of 1524 km. If we presume that the capacity was deployed to support the known and anticipated traffic, then these data suggest that the IP traffic between source and destination on this network tend to decrease with increasing geographic separation. We have illustrated that such correlations can arise in resource-constrained (e.g. cost-constrained) networks even if the constrained resource constitutes only a small fraction of the total resources required to realize and operate the network [9,10]. If a correlation between deployed capacity (or traffic) and distance should be a general characteristic of backbone networks, it may be possible to leverage the known correlations among optical fiber transmission system power margin, distance, and bit-rate to further increase the efficiency and lower the cost of optical networks using bit-rate adaptive transmission [8,11].

5. Traffic, System Capacity and Network Architecture

While the traffic carried on backbone networks and the transmission capacity of fiber-optic systems have both increased considerably since lightwave systems were first deployed, the ratio of total traffic to system capacity has changed considerably [12]. In this presentation we consider the impact this has had on the architecture of backbone networks and by implication how the optical infrastructure, and traffic itself, may change in the future [13].

6. Conclusions and Summary

Given the complexity of continental- and global-scale backbone IP networks, identifying and understanding systematic trends of the traffic in time and space can be useful to guide research that targets new network technologies, architectures, and protocols. Analysis of global backbone traffic growth finds that the growth rate is slowing, but is projected to remain substantial over the coming decades. To provide the required increases in transport capacity, increased channel bit rates, bit-rate adaptive transmission, and spatial multiplexing on the optical fiber are being pursued.

7. References

[1] D C. Kilper, G. Atkinson, S. K. Korotky, S. Goyal, P. Vetter, D. Suvakovic, and O. Blume, “Power trends in communication networks,” *J. Sel. Top. Quantum Electron*. **17**, 275-284 (2011).
[2] Cisco, “Cisco visual networking index: Forecast and methodology, 2009-2014,” June 2, 2010.
[3] A. Gerber and R. Doverspike, “Traffic types and growth in backbone networks,” in *Optical Fiber Commun*. *Conf.* (Los Angeles), 2011, (Optical Society of America, 2011), paper OTuR1.
[4] K. Rinne, “Building next generation mobility networks: Lessons from the Bonneville speedway,” presented at *Conf. Optical Fiber Commun. Conf.* (Los Angeles), 2011, (Optical Society of America, 2011), plenary.
[5] K. Papagiannaki, N. Taft, Z.-L. Zhang, and C. Diot, “Long-term forecasting of Internet backbone traffic,” *Trans. Neural Netw*. **16**, 1110-1124 (2005).
[6] C. Labovitz, “What Europeans do at night,” http://asert.aarbornetworks.com/2009/08/what-europeans-do-at-night/ , 2009.
[7] K. G. Coffman and A. Odlyzko, “The size and growth rate of the Internet,” *First Monday* **3** (10), 1998.
[8] S. K. Korotky, R. J. Essiambre, and R. W. Tkach, “Expectations of optical network traffic gain afforded by bit rate adaptive transmission,” *Bell Labs Tech. J*. **14**, 285-295 (2010).
[9] S. K. Korotky and K. N. Oikonomou, “Scaling of the most likely traffic patterns of hose- and cost-constrained ring and mesh networks,” *J. Opt. Netw*. **7**, 550-563 (2008).
[10] S. K. Korotky and K. N. Oikonomou, “Unified model metrics and constraints for assessing network energy use and cost based on most likely traffic profiles,” in *European Conf. Optical Commun. (Torino)*, 2010, (IEE, 2010), paper P5.16.
[11] O. Rival and A. Morea, “Cost-efficiency of mixed 10-40-100 Gb/s networks and elastic optical networks,” in *Conf. Optical Fiber Commun. Conf.* (Los Angeles), 2011, (Optical Society of America, 2011), paper OTuI4.
[12] R. W. Tkach, “Scaling optical communications for the next decade and beyond,” *Bell Labs Tech. J*. **14**, 3-9 (2010).
[13] S. K. Korotky, “Analysis and optimization of two-tier networks with application to optical transport backbones,” *J. Opt. Netw*. **4**, 45-63, 2005.