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Simulation Based Improvement Study of Overprovisioned IP Backbone Network

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ABSTRACT: *This study provides an insight into the issues involved in the use of computer simulation for improvement of existing IP backbone network operations and management. Most existing IP backbone networks have the problem of being difficult to operate and manage because of the bandwidth overprovision approach that was used for their construction. Simulation is relatively a new technology that is key to design and analysis of communication networks. Not only is it useful for preliminary study of protocols and network applications, it can reveal unexpected system dynamics. Generally, a good network simulator which comprises a wide range of networking technologies and protocols for building complex networks from basic building blocks is essential. In this paper, the traffic data obtained as a result of diverse measurements and analysis from previous studies were used to develop a simulation model of a single hop subnetwork of the Sprints IP backbone network in Riverbed Modeler environment. The simulation results and its analysis revealed a definite change in the performance characteristics of the transmission link which signified an improvement of network operations.*

Keywords *– Computer Simulation, Simulation Model, Bandwidth Overprovision Approach, Network Operations and Management, Riverbed Modeler*

I. INTRODUCTION

The current methodology for addressing the network requirements by backbone network operators is through bandwidth overprovisioning [1]. The resulting network features excess capacity, allowing for transient bursts of traffic, and short-lived network element or link failures [1]. Whenever parts of the network reach utilization levels that could be described as congested, the network operators increase the available capacity lowering the experienced delays, and therefore improving the performance offered to the end user. Such an approach leads to networks that could be described as being continuously "under construction" [1]. New links are added or upgraded weekly increasing the amount of available resources in the network. However, such an approach ends up being rather costly, and given the difficult market conditions, is very hard to justify. As a result, network providers need to find ways in which they could make optimal use of their network's resources and delay future investments as long as possible [1].

Performance and dependability evaluation of modern systems becomes a challenging problem due to the complexity involved. Several solution techniques are available in the literature. One of the most commonly used techniques is the analytic one which produces accurate results. Unfortunately, it becomes inapplicable quickly, due to the size and complexity of models or due to non- Markovian nature of the problem involved [2]. In such cases, approximation methods are applied [2]. Even these approximation methods may become inefficient in most cases, and then simulation becomes inevitable [2]. Simulation is a key technology for the investigation of communication networks [3]. Not only is it useful for preliminary study of protocols and network applications, it can reveal unexpected system dynamics. Generally a good network simulator will comprise of a wide range of networking technologies and protocols and help users to build complex networks from basic building blocks like clusters of nodes and links [4]. With their help, one can design different network topologies using various types of nodes such as end-hosts, hubs, network bridges, routers, optical link-layer devices, and mobile units [4].

In a previous study carried on Sprint IP backbone network [1], a large-scale overprovisioned network in the USA, the results of delay measurements and analysis showed that packet queuing delay can be estimated for only low values of link utilization and does not exceed absolute value for the link. This makes evaluation of the network performance at the usually unpredictable higher loads impossible by actual measurements. Also, the study showed that analytical models underestimate packet queuing delay at lower values of link utilization. Thus, the use of analytical methods for design and performance analysis of large networks is also not reliable. Furthermore, the study found that packet queuing delay is insignificant and dominated by propagation delay in overprovisioned network and asserted that identification and modelling of the several components comprising single-hop delay is necessary for more realistic backbone router models that could easily be used in simulation environments. This shows that the method of network provisioning by bandwidth overprovision has many flaws that lead to an inefficient network and make effective network operation and management a difficult task. In this paper, therefore, the aim is to develop the simulation model of the same subnetwork used in that study and compare its performance characteristics with that of actual measurements and analytical models. The traffic data obtained as a result of diverse measurements and analysis from previous studies were used to develop the simulation model of a single hop subnetwork of the Sprints IP backbone network in Riverbed

Modeler environment. The simulation results and its analysis revealed a definite change in the performance characteristics of the transmission link which signified an improvement of network operations.

The rest of the paper is organized as follows: Section 2 presents the target network. This is followed by a discussion in section 3 on the development of simulation model. The simulation results are presented in section 4. In section 5, the performance analyses are presented. Lastly in section 6 is the conclusion.

II. THE TARGET NETWORK

The topology of an IP backbone network typically consists of a set of nodes known as Points-of-Presence (PoPs) connected through multiple high capacity links []. The Sprint IP backbone consists of approximately 40 PoPs worldwide [5]. Out of these 40 PoPs, approximately 25 are located in the U.S.A. Fig. 1 presents the Sprint IP backbone topology for the continental U.S. Each Sprint PoP is a collection of routers following a two-level hierarchy, featuring (i) access routers, and (ii) backbone routers. Such an architecture is typical among large Tier-1 ISP providers [5]. Access routers are normally lower-end routers with high port density, where customers get attached to the network. These routers aggregate the customer traffic and forward it toward the PoP's backbone routers. The backbone routers receive the aggregate customer traffic and forward it to other PoPs or the appropriate access routers inside the same PoP (in case the destination networks can be reached through the same PoP). Public and private peering points, where one ISP exchanges traffic with other ISPs (usually of the same Tier), are often accommodated by selected backbone routers inside a PoP.

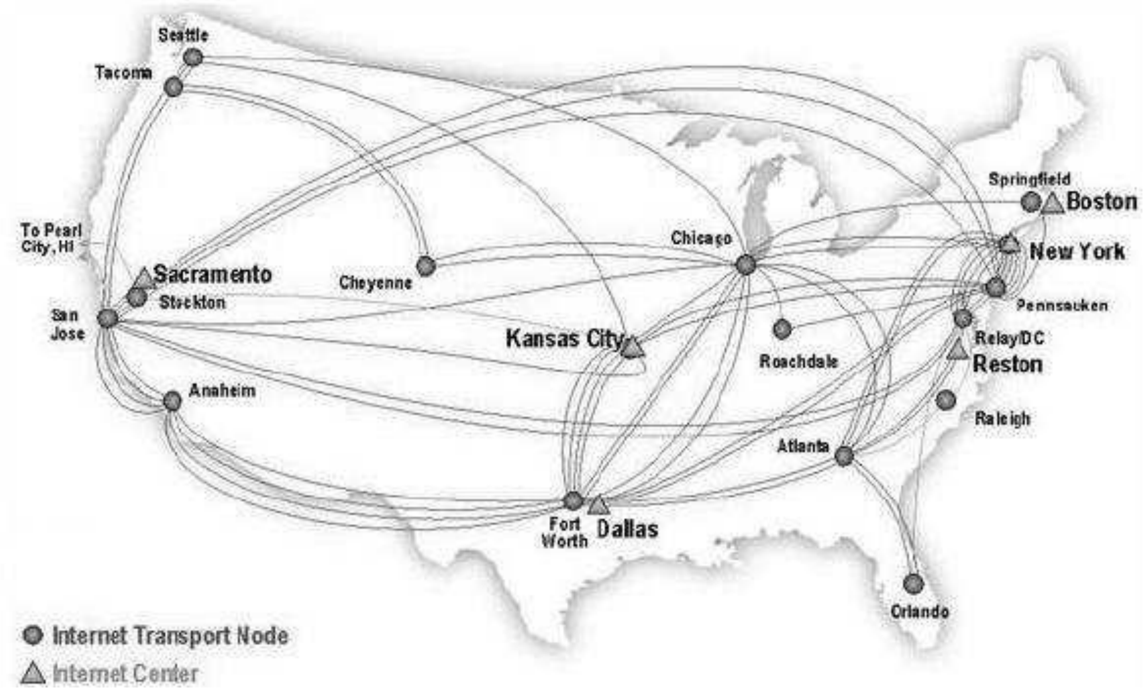

Figure 1. The Sprint IP backbone network topology [5]

III. DEVELOPMENT OF SIMULATION MODEL

The simulation model of the single-hop subnetwork of the Sprint IP backbone network was developed using state-of-the-art Riverbed (OPNET) Modeler [6]. The physical topology of the IP backbone subnetwork is described by a pair of routers and the transmission link interconnecting them. The OSPF is the routing protocol that is used in this study. The OSPF routing protocol has many advantages over other protocols which include the use of dynamic routing, better scalability, faster convergence, etc. [7]. OSPF is also the only completely link-state routing protocol meaning that it is the more efficient; and it is the only open standards routing protocol in use [7]. The OSPF protocol requires the creation of an explicit hierarchical topology rather than the use of addressing for establishment of the topology and segregation of the areas [7].

The single-hop subnetwork topology of the Sprint IP backbone network was optimally developed and converted into simulation model in Riverbed (OPNET) Modeler environment. The Juniper Networks' universal T640 IP router [8] and the high-tech PPP SONET duplex transmission link were configured as the IP and optical layers of the IP backbone subnetwork.

To create the traffic matrix used for this simulation, the traffic data collected from the OC3 backbone link of the Sprint IP backbone network through measurements is used as basis. The details of the measurements are reported in [1] and [5]. Table 1 shows the traffic in packets per second and bits per second respectively starting with the initial value and scaled progressively to emulate and simulate the traffic variation in the network.

Fig. 2 represents the SONET PPP OC3 subnetwork of the Sprint IP backbone network as configured and simulated in the Riverbed Modeler.

Table 1. Traffic table for simulation of the SONET PPP OC3 backbone link

Transmission Link Model	*Traffic in Bits/s*	*Traffic in Packets/s*
SONET PPP OC3	23683010	13580
	35524515	20370
	47366020	27160
	59207525	33950
	71049030	40740
	82890535	47530
	94732040	54320
	106573545	61110
	118415050	67900
	130256555	74690
	142098060	81480
	153939565	88270
	165781070	95060

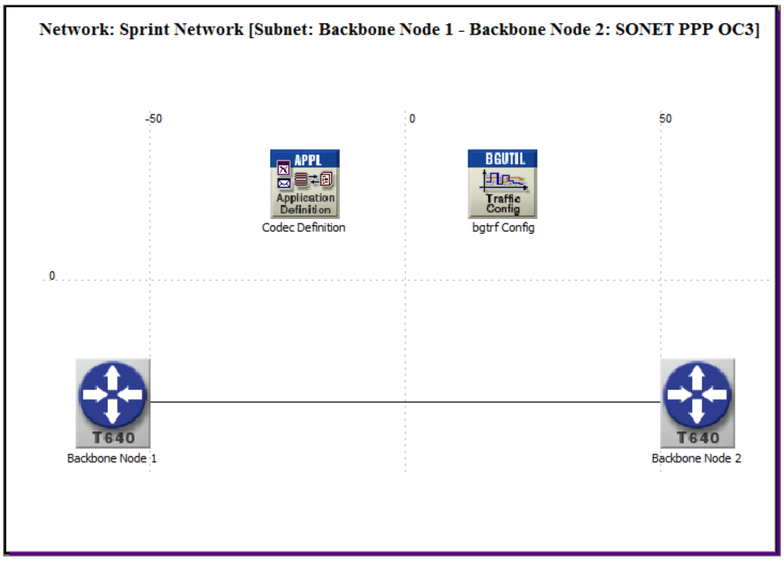

Figure 2. SONET PPP OC3 subnetwork of Sprint IP backbone network as configured and simulated in Riverbed Modeler

IV. SIMULATION RESULTS

The simulation results of the IP backbone subnetwork are shown in Figures 3 and 4. Figure 3 shows the graphs of packet queuing delay and bandwidth utilization for the thirteen steps of traffic variations (see Table 1). The corresponding values of average packet queuing delay and bandwidth utilization are as shown in Table 2. As expected, the packet queuing delay and bandwidth utilization are increasing with traffic load. Figure 4 represents the packet loss performance of the link which was obtained as 0% for all values of traffic. This is also expected because the simulation duration was one hour which may not be sufficient for occurrence of any packet losses especially for the optimally developed network model. It may also be due to rare event probability normally associated with simulation. Also, the MPLS protocol is designed with the capability to suppress packet loss.

Figure 3. Simulation results of queuing delay and bandwidth utilization for the first to the twelfth sets of traffic

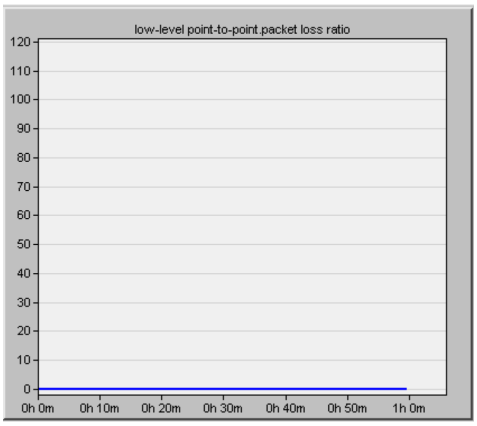

Figure 4. Packet loss ratio for all sets of traffic variations

Table 2. Average queuing delay and bandwidth utilization performance for simulation model of Sprint IP backbone subnetwork

Transmission Link Model	***Queuing Delay (ms)***	***Bandwidth Utilization (%)***
SONET PPP OC3	0.0047	16
	0.0052	23
	0.0060	31
	0.0072	38
	0.0090	46
	0.011	54
	0.014	61
	0.018	70
	0.025	77
	0.042	85
	0.12	91
	1600	95
	1600	95

V. PERFORMANCE ANALYSIS

The performance metrics and set benchmarks are: packet point-to-point queuing delay = 150ms; Average Bandwidth Utilization = 100; Packet Loss Ratio = 0.01 [6], [9]. Queuing delay represents instantaneous measurements of packet waiting times in the transmitter channel's queue [6]. Measurements are taken from the time a packet enters the transmitter channel queue to the time the last bit of the packet is transmitted [6]. Utilization represents the percentage of the consumption to date of an available channel bandwidth where a value of 100 would indicate full usage [6]. Packet Loss Ratio is a Boolean value where 0 represents the acceptance of a packet and 1 the rejection of a packet [6]. The parameters are used for the evaluation of the core transmission links which are the resources mostly affecting network reliability [9]. The analysis is carried out for the backbone transmission link by checking its status against the average values of the performance metrics and benchmarks as displayed by the simulation graphs. Table 2 shows the average values of queuing delay and bandwidth utilization as obtained from the simulation graphs of the OC3 backbone transmission link of the Sprint IP backbone network. Table 3 represents the results of measurements and analysis conducted on OC3 backbone transmission link as reported in [1], [5]. The performance analysis considers the variation of queuing delay with bandwidth utilization. Comparison is made between the performances of the overprovisioned Sprint IP backbone network based on the results of actual measurements and analytical models and the performance of the simulation model of the network. This is illustrated in Figures 5 and 6.

Table 3. Average queuing delay and bandwidth utilization derived from measurements and analysis of Sprint IP backbone subnetwork

Bandwidth Utilization (%)	***Queuing Delay (ms)***	
	Measurements	***Analytical Models***
0	-	0.00001
10	-	0.003
20	0.01	0.005
30	0.02	0.008
40	0.04	0.01
50	0.06	0.02
60	0.1	0.04
70	0.2	0.06
80	-	0.1
90	-	0.2
100	-	1000

Figure 5 represents the variation of single-hop packet queuing delay with bandwidth utilization with the performance of the simulation model plotted on the same axes as the actual measurements and analytical models of the Sprint overprovisioned backbone network for the entire utilization region. It can be seen that the three graphs compare favorably for link utilizations up to the normal 70%. However, for the higher and lower regions of link utilizations, only variation for the analytical and optimally developed models are noticed with both exhibiting congestion at the untypical utilization region beyond 90%. It can be seen that the queuing delay for analytical models within this region is dominant, which implies an overestimation of queuing delay. The main conclusion reached is that, queuing delay variations are not obtainable at link utilizations higher than the absolute value of the link from actual measurements in an overprovisioned

IP backbone network and analytical models underestimate the queuing delay at the lower and intermediate utilization regions and overestimates the queuing delay at higher utilization regions. This condition makes it difficult to predict the actual behavior and achieve the effective operation and management of an overprovisioned network.

Figure 6 is alternative graph of the average queuing delay versus link utilization derived from actual measurements, analytical models and optimally developed model of the Sprint IP backbone network. The graph clearly shows that the queuing delay performance is dominated by the optimally developed model at both lower and intermediate utilization regions and is moderate at the higher regions, which depicts a more appropriate behavior of the network.

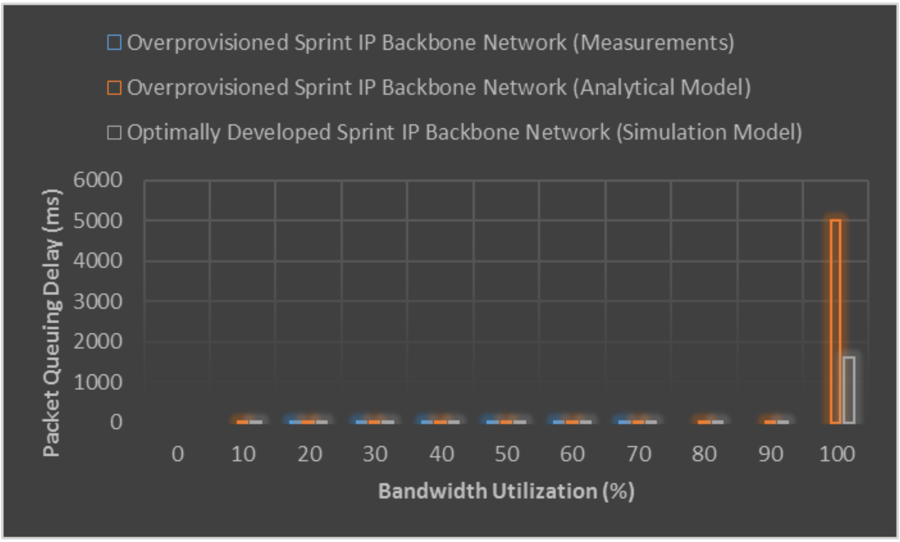

Figure 5. Average queuing delay versus link utilization derived from actual measurements, analytical models and simulation model of the Sprint IP backbone network

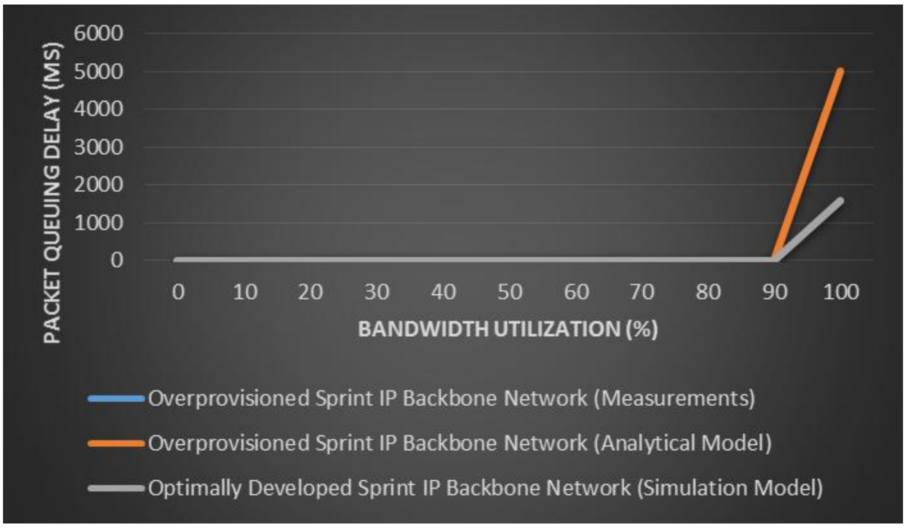

Figure 6. Alternative graph of average queuing delay versus link utilization derived from actual measurements, analytical models and simulation model of the Sprint IP backbone network

VI. CONCLUSION

It clearly evident from this study that, network requirements and performance analysis of IP backbone networks developed by the method of bandwidth overprovision is not dependable and hence its operation and management is difficult and heavily dependent on human operators. On the other hand the optimally developed IP backbone network simulation model shows realistic performance with all performance metrics throughout the utilization region and hence would be easy to operate and manage and unnecessary rearrangement of network resources will be obviated. Moreover, the systematic modelling and simulation process enables the iterative development of a scalable and cost-effective network model by specifying the best utilization region to operate and manage the network.

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