Flow-based analysis of Internet traffic

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Abstract

We propose flow-based analysis to estimate quality of an Internet connection. Using results from the queuing theory we compare two expressions for backbone traffic that have different scopes of applicability. A curve that shows dependence of utilization of a link on a number of active flows in it describes different states of the network. We propose a methodology for plotting such a curve using data received from a Cisco router by NetFlow protocol, determining the working area and the overloading point of the network. Our test is an easy way to find a moment for upgrading the backbone.

Key words: Flow-based test of network quality, Cisco NetFlow, queuing models, Passive Monitoring System

1 Introduction

Modeling the traffic at the packet level has proven to be very difficult since traffic on a link is the result of a high level of aggregation of numerous flows. Recently, a new trend has emerged, which consists in modeling the Internet traffic at the flow level. A flow here is a very generic notion. It can be a TCP connection or a UDP stream described by source and destination IP addresses, source and destination port numbers, and the protocol number. It is possible to get an idea about the response time of a flow and about the distribution of the flows that are active at a certain time in the network. From a simplicity

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standpoint, it is much easier to monitor flows than to monitor packets in a router.

Network operators need to know when their backbone or peering links have to be upgraded. As a clue for this, boundary values of network parameters may serve - as the current values of the network parameters reach some limit values, the links have to be upgraded. The problem is that there is no common view point on the set of parameters to monitor and on their boundary values. Each provider has its own technical specifications aimed on avoiding overloading and big providers, like Sprint [6], rely on the results of their own researches. Usually, network operators monitor peak and average link utilization levels and upgrade their links when utilization level lays in the range 30%-60%.

Academic research community should play an important role in providing analytical generalization and establishing common terminology for processes taking place in networks. Our aim is a paper where we accumulate our knowledge about the network quality and related terms like length of working part, points of overloading and etc, as well as to formulate basic recommendations for the moments for upgrading links. Traffic measurement and analysis should be extended to consider the case of a single path (hop) between two routers on a high-speed backbone. This lets to find bottlenecks on backbones like GEANT. Usually, network operators collect statistics on packet level that include source and destination addresses, ports, protocols, packet flags, size, start and end time of UDP and TCP sessions, duration of the sessions and etc. Processing of such huge volume of data is a difficult task demanding powerful hardware, software, big human efforts, but, unfortunately, it does not always let to get enough information to give some recommendations for the network under consideration.

The contribution of the paper is a simple flow-based test to find a moment for upgrading of a backbone. In the next Section we use queuing theory for flow-based analysis of a backbone. Section 3 discusses three states of a network with different performances. A test for network quality is described in the Section 4. The results of the experiments conducted in the real networks of ISPs are given in the Section 5.

2 The model

In this paper we model traffic as a stationary stochastic process, using the results from the papers Barakat et al [2] and Ben Fredj et al [3].

In summary, presented model allows us to completely characterize the data rate on a backbone link based on the following inputs:
Session arrivals in any period where the traffic intensity is approximately constant are accurately modeled by a homogeneous Poisson process of finite rate $\lambda$. In general, this assumption can be relaxed to more general processes such as MAPs (Markov Arrival Processes) [1], or non-homogeneous Poisson processes, but we will keep working with it for simplicity of the analysis.

The distributions of flow sizes $\{S_n\}$ and flow durations $\{D_n\}$. In this paper we denote by $T_n$ the arrival time of the $n$-th flow, by $S_n$ its size (e.g., in bits), and by $D_n$ its duration (e.g., in seconds).

The flow rate function (shot) is $X_n(\cdot)$. A flow is called active at time $t$ when $T_n \leq t \leq T_n + D_n$. Define as $X_n(t - T_n)$ the rate of the $n$-th flow at time $t$ (e.g., in bits/s), with $X_n(t - T_n)$ equal to zero for $t < T_n$ and for $t > T_n + D_n$. In other words, $X_n(t - T_n)$ is zero if flow $n$ is not active at time $t$.

Define $R(t)$ as the total rate of data (e.g., in bits/s) on the modeled link at time $t$. It is the result of the addition of the rates of the different flows. We can then write

$$R(t) = \sum_{n \in \mathbb{Z}} X_n(t - T_n) \quad (1)$$

The process from Eq. (1) can describe the number of active flows found at time $t$ in an $M/G/\infty$ queue [7], if $X_n(t - T_n) = 1$ at $t \in [T_n, T_n + D_n]$.

The model presented by Barakat et al [2] is able to compute the average and the variation of the backbone traffic. In summary:

- The average total rate of the traffic is given by the two parameters $\lambda$ and $\mathbb{E}[S_n]$:
  $$\mathbb{E}[R(t)] = \lambda \mathbb{E}[S_n] \quad (2)$$

- The variance of the total rate $V_R$ (i.e., burstiness of the traffic) is given by the two parameters $\lambda$ and $\mathbb{E}[S_n^2/D_n]$:
  $$V_R = \lambda \mathbb{E}[S_n^2/D_n] \quad (3)$$

It should be mentioned that Eq. (2) is true only for the ideal case of the backbone link of unrestricted capacity that can be applied to underloaded links. The arrival rate of flows $\lambda$ describes the user’s behaviour that doesn’t depend on the network utilization. The cumulative number of flows that arrive at a link will remain linear even if the network doesn’t satisfy all the incoming demands. The average flow size does not also depend on a specific system, but only on the current distribution of documents sizes found in the Internet. Thus the main drawback of the ratio (2) is lack of its definite usage limits, which is the result of the fact that variables describing the system are in no way connected with its current state.
Ben Fredj et al [3] consider a case where the link capacity $C$ is very large compared to the external rate limits and such that it is virtually transparent. By this they mean that the probability that the sum of external rate limits of all active flows exceeds link capacity $C$ is negligibly small. This assumption is reasonable for the large, moderately loaded links of major backbone providers.

The number of active flows is now unconstrained by the considered link which appears as an $M/G/\infty$ queue. Let $E[D_n]$ be the mean duration of flow and $N$ the mean number of active flows. By Little’s law we have:

$$N = \lambda E[D_n]$$ (4)

This formula describes the network state more precisely as the average number of active flows on the bandwidth unit increases with the utilization. In other words, the average duration of flow enables us to judge the real network state in contrast to its average size.

### 3 Performance states on flow level

Analyzing the Eqs. (2) and (4) we may compare the ideal and the real states of the network link under consideration. In order to analyze the quality of the backbone area or link to provider we are going to construct a graphical dependence between the link loading and the number of active flows in it.

The suggested curve has been found on Fig. 1. On the given curve three parts corresponding to the different network states can be identified.

The first part of the curve highlighted in green describes the network state close to the ideal, which coincides with the domain of applicability of the more strict state equation (2). The possibility of an error considered, the points corresponding to the real network states are supposed to be on the straight line, which corresponds to the working network area. The end of the straight line, which can be found from an experiment, defines thus the length of the working area.

The second part of the curve highlighted in yellow corresponds to the moderately loaded network. This parts coincides with the scope of less strict equation of state (4), when the diversion from the ideal network state becomes obvious. Increased average duration of a flow compared to the working area and therefore a larger number of active flows on the bandwidth unit are characteristic of this network state.

The red part of the curve corresponds to the totally disabled network with
considerable loss of packets.

4 Test for network quality

In order to prove our hypothesis we made experiment on border gateway routers of Ireland National Research and Education Network - HEANet and Russian ISP "SamaraTelecom". Both networks have several internal and external links but basic load lies on one channel to Global Internet (622 Mbps for HEANet, 8 Mbps for ST). The utilization of these links varies in wide limits from 5% to 90% with a clearly identifiable busy period.

A passive monitoring system based on Cisco’s NetFlow [5] technology was used to collect values of links utilization and number of active flows in real-time.

We measured on the Cisco 7206 router with NetFlow switched on. The detailed description of Cisco NetFlow can be found in documentation of Cisco [5].

It should be mentioned that exporting of flows is to be switched on all interfaces from which the data is to be collected. Otherwise the data obtained while measuring won’t contain complete information. For example, we didn’t quite succeed in our experiment with Ireland National Research and Education Network (HeaNet) because of the incomplete setup of NetFlow support on the routers. Usually a network has only one or a few external links while
internal connections remain considerably less loaded. That's why we can construct dependence of the number of all active flows on the boundary router on the general loading of the external links. It is achieved by the following commands:

- `sh ip cache flow` - gives information about the number of active and inactive flows, about the parameters of the flows at the real time.
- `sh int [a name for the external interface]` - gives information about the current link loading.

The data obtained with the commands contain all the necessary values for the construction of the curve similar to the one drawn in Fig. 1. The values are to be recorded twenty-four hours a day every 30 minutes during a week to discover network behaviour while differently loaded. It’s quite easy to write a script, which will collect the data from the router to the management server.

5 Experimental validation

It has already been mentioned that such a test has been conducted on the boundary router of Samara Telecom Company. As external links four E1 links (4 x 2.048 Mbit/s) to different ISP were used. We have taken a number of points for different network loading states. The results of this measurement are represented on Fig. 2. On the X axis there is the number of flows and on the Y axis there is the network loading in percents from its maximal value.

The separate points on the curve from Fig. 2 correspond to the real network states and the discrete straight line, which consists of dashes of different length, depicts the ideal network behaviour corresponding to the Eq. (2). The angle of of this straight line is found as average of $U/N_a$ ratio taken from the states when the network loading didn’t exceed 40%.

The working area is limited from the top by a straight dotted line, which is the nearest approach to the description of the network behaviour when the load-
ing is heavy. The crossing of the two straight lines allows finding the length of the working area (45%). When the number of flows is more than 2500 network experiences overloading which leads to the slowing down of the speed of the network connections. The overall link loading practically doesn’t increase along with the amount of requests and the connection quality becomes almost twice as bad. It should be mentioned that in the network under consideration transition area or moderately loaded network doesn’t virtually exist. (see Fig. 1). The experiment conducted is evidence of the fact that providers do not always guarantee the work within the working network area which is especially important for the applications requiring high network quality, for example, IP telephony and videoconferencing. At the hours when the network loading was the heaviest the actual network capacity proved to be nearly twice as low as stated.

6 Feature work

In this paper some methods are described which allow us to evaluate Internet link quality on the base of flow technology and increase their capacity in time. At the moment we are working on developing utilities, which will make it possible to construct dependence of link loading on the number of active flows automatically and calculate the length of the working area.

We also plan further research work, which suggests evaluation of the flow parameters and above different speed of data transfer. We propose to derive analytic dependence of flow speed, i.e. to evaluate the time of transfer of file of a certain size between the two remote IP addresses (end-to-end) on the packet delivery time and percentage loss. In other words to theoretically evaluate connection quality according to ping data and its analogue for TCP packets.

Unfortunately, low-speed Russian Internet links are only available for our research work. Our attempts to collect the necessary data from high-speed international links with preferable speeds of 622 Mbps and 2.4 Gbps failed. As we know from our own experience one can get the data in a necessary format only through personal communication with the staff of the researched network. That’s why we need assistance and joint projects for financing the trips to the place of research work.
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