QoS Predictability of Internet Services

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Abstract. The paper[1] presents problems of QoS (Quality of Service) predictability of network services (mainly in WAN environment). In the first part we present general remarks on QoS predictability problem, mentioning some research projects and available resources. The main part of the paper deals with QoS predictability in long-term as well as short-term viewpoints. We will try to answer a question: is it possible to predict network QoS/performance level with a use of statistical data from the past? The term quality of service has many meanings ranging from the user's qualitative perception of the service to a set of quantitative connection parameters (RTT (Round Trip Time), throughput, loss packet rate) necessary to achieve particular service quality. In the paper we will mostly use the second meaning of the term based on RFC 2386 [1]. Analyzed, statistical data on Internet performance are taken from the IEPM (Internet End-to-end Performance Measurement) database.

Keywords: QoS, throughput, RTT, lost packet rate.

1 Introduction

The number of interactive, real time services (e.g. Voice over IP) and critical network-oriented applications (such as MRP (Material Requirement Planning), SAP (Systems Applications and Products)) is growing. The services impose strict requirements on network QoS. On the other hand QoS in a given communication channel is dependent on many diverse factors. Not all of them are manageable and predictable. The question is: is it possible to find regression trend approximating statistical data, is it possible to forecast/guess QoS and network performance level with a use of data from the past? We will try to answer the question from 2 viewpoints: long-term (years) and short-term (days). In general, IT performance parameters (processor power, data bandwidth) improve in time. From the predictability point of view we may divide the parameters into two types: with or without practical limits. For example RTT for any network has minimum value that could not be crossed due to physical limitations such as signal propagation speed limit (e.g. electrical signal travels through copper wire at 182 000 km/s). Other parameters (e.g. throughput) also have limitations but in practice they are very distant from current values of the parameters.

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For example typical throughput available for common user on Internet connection is measured in Mbit/s while optical fiber bandwidth reaches Tbit/s. The term QoS is defined in the paper as a set of quantitative connection parameters (delay, jitter, throughput, loss packet rate) with throughput and RTT/delay recognized as most important. In the case of such services as VoIP it is important if values of the connection parameters are not below some thresholds (e.g. for speech coded with ITU G.711 throughput should not drop below 90 kbit/s).

2 Research Projects and Resources

Network performance and quality of Internet services is an important research topic. Many different tools and services have been designed and implemented, for example: IEPM at Stanford Linear Accelerator Center, MWING at Wroclaw University of Technology [2]. The Software Predictability Group[2] from Department of Computer Science on The University of Virginia is working on such topics as: QoS Control, QoS Portability and architectures for QoS on the Web. Internet performance measurement is also business area with commercial tools and services, for example Keynote's test and measurement products and services[3]. Furthermore, number of protocols for QoS optimization on different TCP/IP layers are introduced and tested (e.g. [3]). There are also forecasts estimating Internet growth rates, e.g. Cisco Visual Networking Index predicts that in 2008–2013 overall, IP traffic will grow at a compound annual growth rate of 40% [4]. Analysis presented here is based mainly on statistical data taken from the IEPM database operating since 1995 and collecting Internet performance measurements since 1998 [5].

3 Long Term QoS Predictability

Predicting average QoS level of Internet services in months and years perspective is a complex, multidimensional problem. One has to take into account many technological, economic, social factors, such as number of hosts, services, users, cable deployment, bandwidth, router performance. The status quo is roughly known but future is hardly predictable, e.g. Moore's law is no more satisfied.

As an example we will analyze changes in average QoS factors for Europe to North America connections. Transatlantic Internet connections between Europe and North America are based on submarine cables. With growing number of hosts and Internet services the traffic increases quickly. In general, theoretical fiber capacity growth as well as router performance growth roughly keep pace with growing user demands [6]. Nevertheless new submarine cables deployment is sluggish and irregular (e.g. last new transatlantic cable was deployed in 2003) and no new cables are planned for next two years[4]. Data on transatlantic cables are based on ICPC (International Cable Protection Committee) resources [www.iscpc.org].

[2] http://www.cs.virginia.edu/qos/
[3] http://www.keynote.com
[4] http://www.atlantic-cable.com/Cables/CableTimeLine/index2001.htm

It may be assumed that total capacity of North Atlantic cables operated in 1998 was equal roughly to 170 Gbit/s. Several new cables were deployed between 1999 and 2003. The total capacity grew to about 19 Tbit/s. So we have roughly 110-fold increase in available bandwidth[5].

Throughput. From the user point of view total bandwidth is less important than data throughput. One may assume that data throughput (available for a given user) growth would be equivalent to bandwidth growth. Statistical data show that the two rates of progress are dissimilar (Table 1) (the transatlantic communication channels are asymmetric, the parameters for two directions (USA to Europe and Europe to USA) are different. USA to Europe throughput is worse than Europe to USA, the table presents average values for both directions and between 150 and 550 different connections[6]). From 1998 to 2009 the total capacity of submarine cables increased about 110 times, while throughput increased just 6-fold. Despite fast and numerous advances in physical layer, link layer and new telecommunication cables deployment network performance measures are hardly progressing. Furthermore, the average yearly throughput is hardly predictable since it is not growing monotonously (Fig. 1). There are periods (1998–2005) of approximately linear growth (+0.32 Mbit/s/year)). On the other hand in 2005–2007 we may observe decrease from 2.5 to 1.8 Mbit/s and in 2008–2009 average throughput is constant. Year to year changes are in the range from -0.5 Mbit/s (2006/2007) to +0.9 Mbit/s (2007/2008).

Table 1. Changes in performance parameters for transatlantic connections in 1998–2009 [http://www-wanmon.slac.stanford.edu/cgi-wrap/pingtable.pl]

Year	Total capacity of cables [Tbit/s]	Average throughput [Mbit/s]	Average RTT [ms]	Median jitter [ms]	Packet loss rate [%]
1998	0.17	0.46	228	0	5.2
1999	0.21	0.48	223	0	4.1
2000	0.85	0.72	188	2.0	2.6
2001	16	1.2	202	3.4	1.4
2002	16	1.4	189	3.0	1.0
2003	19	1.8	166	1.8	1.0
2004	19	2.3	157	1.5	0.6
2005	19	2.5	156	1.0	1.6
2006	19	2.3	163	0.8	1.4
2007	19	1.8	163	0.8	3.3
2008	19	2.7	165	1.1	0.7
2009	19	2.7	162	1.1	1.7

[5] It may be observed that Ethernet bandwidth is also growing exponentially from 10 Mbit/s in 1989 to 100 Gbit/s in 2010 – this means 10 000-fold increase in 20 years.

[6] The number of tested connections changes in time.

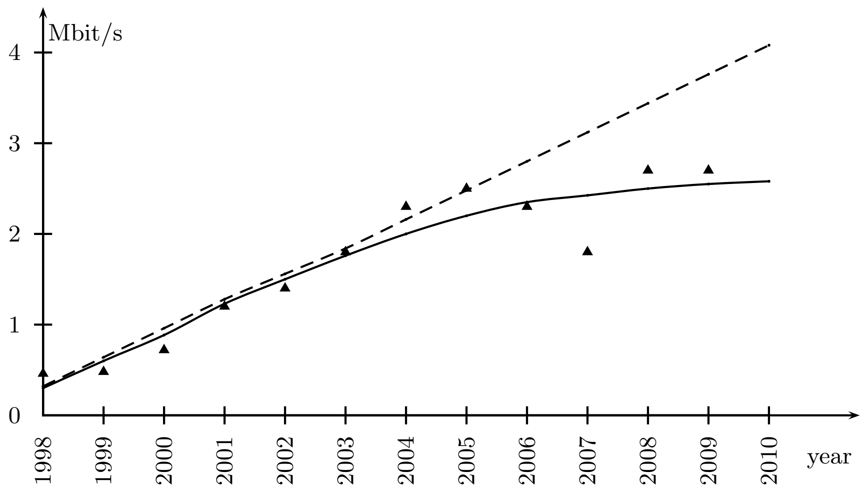

Fig. 1. Statistical data on throughput with linear regression line (based on data for 1998–2005) and polynomial regression line (based on data for 1998–2009)

Going back to 2005 and trying to predict average throughput for year 2009 we have only data from 1998–2005. Assuming best approximation with linear regression (Fig. 1 dashed line),

$$y = 0.3193x - 0.0793 \tag{1}$$

where $x = year - 1998$, in 2009 throughput should be at the level of 4.08 Mbit/s. It is obvious that value predicted this way is far from accurate. On the other hand going back to 2008, using data from 1998–2008 and assuming best approximation with polynomial regression (Fig. 1, solid line)

$$y = 0.0151x^2 + 0.4107x - 0.1573 \tag{2}$$

in 2009 throughput should be at the level of 2.58. The value is slightly below the measured one (Fig. 1), so the approximation is well fitted. However, observing statistical data from the past one is not able to guess if this polynomial trend will hold on in next years.

RTT and Jitter. Another important QoS parameter is RTT. It is rather loosely related to number of submarine cables and their capacity. For a given communication channel RTT is dependent on routers' performance and their load. The router performance, which takes advantage of the Moore's Law[7] increases at approximately the same rate as processor power. For transatlantic connections, in 1998–2004 average RTT drops from 228 ms to 157 ms (about -11 ms/year), in

[7] For years it was assumed that, according to Moore's law [7], processing power doubles every 18 months. Nowadays the assumption is negated even by the author of the law [http://www.techworld.com/opsys/news/index.cfm?NewsID=3477].

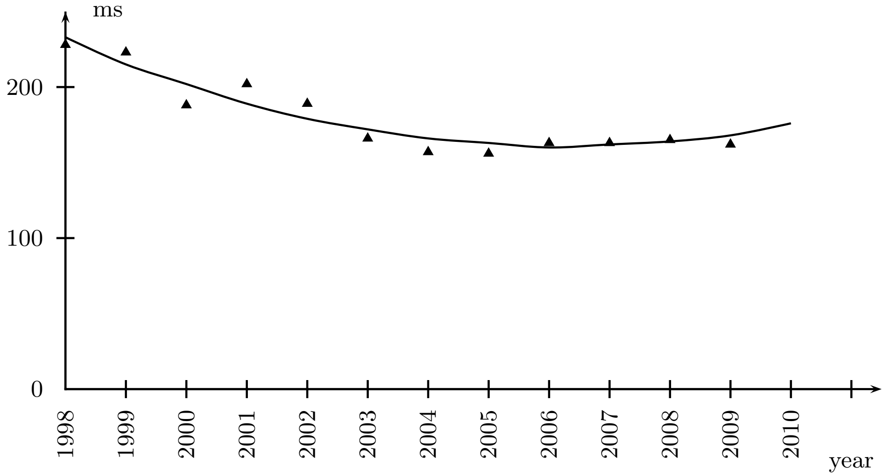

Fig. 2. Statistical data on RTT with polynomial regression line

the period 2004–2009, average yearly RTT is more or less predictable and constant. There are only minor fluctuations (±5 ms). Using data from 1998–2008 and assuming polynomial regression (Fig. 2, solid line)

$$y = 1.0932x^2 - 19.973x + 251.37 \tag{3}$$

where $x = year - 1998$, in 2009 RTT should be at the level of 167 ms (the value is near the measured one) (Fig. 2). It may be assumed that 100–110 ms is a minimum value of RTT (in the case of hosts topologically near submarine transmit and receive terminals and a minimum number of routers) and no further improvement is possible because of physical limitations. Typical length of North Atlantic cable is between 6000 and 7500 km. The speed of infrared waves in a fiber is close to 220 000 km/s, so the signal travels one way through the cable in 27–34 ms. In the worst case transmit terminal in submarine fiber system adds 13 ms delay and receive terminal 10 ms [8]. So one way signal propagation time (excluding delays in routers) is about 40–50 ms.

Average jitter in the given period fluctuates highly due to temporary problems on some tested connections (see Sect. 4). Median of jitter is much more stable, in the last 5 years it stays in the range of 0.8–1.1 ms.

In the last 10 years average lost packet rate fluctuates between 0.6 and 3.3% It must be noted that lost packet rate above 2.5% means bad quality of real time voice transmission.

4 Short Term QoS Predictability

Predicting QoS level in short term (days) perspective should be easier assuming there are no extraordinary incidents. In normal operation average values of network parameters do not change rapidly.

4.1 Throughput

Table 2 presents average monthly (December 2009) and yearly (2009) values of throughput together with daily throughput values from January 2010 for North America to Europe Internet connections (average values for 184–202 connections). In the case of N. America to Europe connections minimum value of daily throughput in January 2010 drops significantly below average minimum values for 2009 and December 2009. Average and maximum values in January 2010 are relatively constant (average – 1.88–2.06 Mbit/s, maximum – 3.40–3.60) but much worse than average and maximum for December 2009. So predicting January data with a use of December statistics give us overestimated numbers.

Table 2. Exemplary fluctuations of throughput in January 2010 for N. America to Europe connections [http://www-wanmon.slac.stanford.edu/cgi-wrap/pingtable.pl]

Date	Minimum [Mbit/s]	Average [Mbit/s]	Maximum [Mbit/s]	Std deviation [Mbit/s]
2009	1.12	2.61	8.70	1.74
Dec 2009	0.06	3.89	18.0	3.25
Jan 1, 2010	0.21	2.06	3.52	0.64
Jan 2, 2010	0.32	2.05	3.41	0.55
Jan 3, 2010	0.30	2.06	3.40	0.57
Jan 4, 2010	0.18	2.05	3.48	0.68
Jan 5, 2010	0.08	2.01	3.41	0.68
Jan 6, 2010	0.06	2.01	3.52	0.67
Jan 7, 2010	0.06	1.94	3.40	0.63
Jan 8, 2010	0.07	1.88	3.48	0.63
Jan 9, 2010	0.03	1.94	3.60	0.67
Jan 10, 2010	0.05	2.00	3.60	0.68

Table 3. Exemplary fluctuations of throughput in January 2010 for Europe to N. America connections [http://www-wanmon.slac.stanford.edu/cgi-wrap/pingtable.pl]

Date	Minimum [Mbit/s]	Average [Mbit/s]	Maximum [Mbit/s]	Std deviation [Mbit/s]
2009	0.96	2.84	6.80	1.64
Dec 2009	1.09	4.11	11.5	2.34
Jan 1, 2010	1.17	2.45	3.66	0.64
Jan 2, 2010	0.58	2.44	3.68	0.71
Jan 3, 2010	0.55	2.44	3.68	0.70
Jan 4, 2010	0.55	2.30	3.58	0.76
Jan 5, 2010	0.32	2.18	3.68	0.84
Jan 6, 2010	0.28	2.28	3.68	0.80
Jan 7, 2010	0.73	2.40	3.65	0.74
Jan 8, 2010	0.98	2.43	3.67	0.68
Jan 9, 2010	0.87	2.43	3.69	0.67
Jan 10, 2010	0.69	2.40	3.64	0.80

Table 3 presents average monthly (December 2009) and yearly (2009) values of throughput together with daily throughput from January 2010 for N. America to Europe Internet connections (average values for 47–50 connections). In the case of Europe to N. America connections daily minimum throughput in January 2010 drops to roughly 1/4 of average minimum values for 2009 and December 2009. Average and maximum values in January 2010 are relatively constant (average in the range of 2.18–2.45 Mbit/s, maximum – 3.58–3.69) but worse than average and maximum for December 2009 and year 2009. So predicting January data with a use of December statistics would gives us overestimated numbers.

4.2 RTT

Table 4 presents average monthly (December 2009) and yearly (2009) values of RTT together with daily RTT from January 2010 for North America to Europe Internet connections (average values for 184–202 connections). Table 5 presents average monthly (December 2009) and yearly (2009) values of RTT together with daily RTT from January 2010 for N. America to Europe Internet connections (average values for 47–50 connections). In both cases minimum as well as average values of RTT in the first days of January 2010 are next to average values for December 2009 and for year 2009 – the differences are not more than 10% with standard deviation not exceeding 40 ms. The same is true also for maximum RTT in Europe to N. America connections. Nevertheless maximum RTT for reverse direction changes highly up to 170% of December 2009 value and 340% of 2009 value with standard deviation exceeding 110 ms (January 9, 2010).

4.3 Weekdays Fluctuations of Network Performance Level

Some minor fluctuations are visible in the average QoS values of particular days of week. Throughout a given period of time (e.g. year) Saturdays and Sundays

Table 4. Exemplary fluctuations of RTT in January 2010 for N. America to Europe connections [http://www-wanmon.slac.stanford.edu/cgi-wrap/pingtable.pl]

Date	Minimum [ms]	Average [ms]	Maximum [ms]	Std deviation [ms]
Year 2009	105	171	249	29
Dec 2009	104	179	504	59
Jan 1, 2010	103	177	411	44
Jan 2, 2010	103	172	224	27
Jan 3, 2010	103	171	229	27
Jan 4, 2010	104	172	338	37
Jan 5, 2010	106	180	527	61
Jan 6, 2010	105	184	660	80
Jan 7, 2010	106	182	673	85
Jan 8, 2010	103	179	541	66
Jan 9, 2010	102	188	840	115
Jan 10, 2010	103	183	782	99

Table 5. Exemplary fluctuations of RTT in January 2010 for Europe to N. America connections [http://www-wanmon.slac.stanford.edu/cgi-wrap/pingtable.pl]

Date	Minimum [ms]	Average [ms]	Maximum [ms]	Std deviation [ms]
Year 2009	102	154	203	30
Dec 2009	101	150	201	30
Jan 1, 2010	101	147	198	30
Jan 2, 2010	100	147	198	30
Jan 3, 2010	100	148	197	30
Jan 4, 2010	102	148	203	30
Jan 5, 2010	100	156	222	37
Jan 6, 2010	100	155	218	37
Jan 7, 2010	101	148	198	29
Jan 8, 2010	101	149	198	30
Jan 9, 2010	100	148	199	30
Jan 10, 2010	102	148	198	30

have the best average QoS (the highest average throughput and the lowest average RTT) Mondays have the worst. Nevertheless in a given week of the year it is not possible to predict a day with the highest QoS level [9].

4.4 Unpredictability of QoS in the Case of Disasters

QoS is disrupted by many, intentional and unintentional factors: malicious software, spam, hackers and disasters (e.g. earthquakes). First 3 factors are widespread and hardly predictable. Damages imposed are usually short-lived and restricted to single service. On the other hand disasters are uncommon, almost unpredictable, their impact is long-lived (up to several months of degraded QoS). They disrupt Internet services, telephone calls and ATM transactions. Intercontinental cable faults are relatively infrequent (in 2003 annual fault rate was at the level of 1 fault per 10 000 km of cable [10]). In the Atlantic, cable breaks happen repeatedly (above 50 cable repairs are yearly). Submarine cables are prone to being affected by earthquakes, storms, fishing equipment and anchors (Table 6).

The disaster's impact on QoS is: significant, long-lived and widespread (due to rerouting of damaged connections). The performance parameters during the accidents decrease in some cases to unacceptable (for interactive applications) levels. Internet performance is changing in unpredictable way. The effects of submarine cable cut accident are notably different from the effects of hacker attack on Internet server. Similar accidents in the future should be expected. Generally we are not able to predict time and place of the accidents (e.g. earthquakes are hardly predictable). Case study of January 2008 accident is presented in [11].

Table 6. Recent disasters with submarine cable faults

Date	Damaged cables	Cause of cable fault	Time of QoS degradation
May 2003	5 cables near Algiers	earthquake	6 weeks
Nov 2003	TAT-14 (USA-Europe)	technical fault	few days
Jun 2005	SMW 3 (Pakistan)	unknown	12 days
Dec 2006	CANTAT-3 (Iceland-Europe)	unknown	7 months
Dec 2006	7 cables near Taiwan	earthquake	7 weeks
Jan 2008	SMW 4, FLAG, FALCON	anchors	2 weeks
Dec 2008	SMW 3, SMW 4, FLAG	earthquake	unknown

5 Conclusions

It is easy to conclude that QoS prediction is a hard problem especially in long-term perspective. How to determine future if such basic and general principles as Moore's Law are no more fulfilled. Intercontinental connections performance is upgrading very slowly and irregularly. QoS is related to a few network performance parameters. Some of them are easier to predict than others. Such parameters as average RTT are relatively stable, on the other hand throughput fluctuations are large.

Compound growth of throughput for exemplary transatlantic connections in 10 years is just 6-fold on average. The increase rate is lagging behind other computer and network performance indicators. At the same time total North Atlantic bandwidth increased approximately 110 times. This is related to fiber transmission capacity and DWDM link speed, which grow by a factor of about 200 in the decade. Similarly, computer power increase in the same period is 100-fold. The router capacity increases at approximately the same rate. Predicting average parameters (in particular throughput) in long-term perspective is hardly possible, even with a use of great number of statistical data. Many factors should be taken into account. The values of the parameters (e.g. throughput) slowly improve in time but the improvement is not monotonous and very loosely related to more or less predictable factors such as communication channel bandwidth or processor (router) performance. Approximating statistical data with regression trends is hardly possible. We have shown that the best approximation for some sets of older data is linear regression. Unfortunately this regression type is useless if we take into account more recent data.

In short-term perspective it is much easier to predict QoS level, assuming there are no extraordinary incidents. In normal operation average values of network parameters do not change rapidly. Nevertheless irregular disasters with submarine cable faults make this predictability more complicated. Significant QoS deterioration together with high fluctuations of performance parameters may last weeks and even months.

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