Tuning Active Monitoring in Multi-service IP Networks

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Abstract. This paper explores the use of edge-to-edge active monitoring to control simultaneously multiple QoS parameters in multi-service IP networks, while reducing the effects of intrusion on real traffic. Considering a multi-class domain where traffic is controlled at network boundaries based on feedback from on-line measurements, the present work is centered on obtaining adequate per class in-band probing streams so that each class behaviour is correctly captured, even if more than a QoS metric is under control. In this way, we investigate distinct properties of probing patterns and cross-check probing and passive measurement results in order to assess and tune probing effectiveness. To enhance probing ability to sense multiple metrics, we explore Active Queue Management effects on probes and their different probability of reaching the network boundary. The results show that, while IPTD can be easily captured using a very low probing rate, matching ipdv and IPLR is not straightforward. However, we found that choosing a convenient drop precedence for probing packets, the simultaneous estimation of these QoS metrics can be significantly improved.

Keywords: Active Monitoring; Traffic Control; Quality-of-Service; Multi-service Networks

1 Introduction

The widespread use of high-speed networks and multimedia capable end-systems have encouraged the development of distributed multimedia applications highly demanding in terms of network resources and quality of service (QoS) requirements. To face the heterogeneous demand in multi-service networks, Internet service providers are adopting class-based models, such as Diffserv [1, 2], so that distinct quality of service (QoS) profiles and service level specifications (SLS) are fulfilled. Active monitoring carried out on an edge-to-edge basis, i.e. between the network boundaries in which a service level needs to be enforced, is particularly suitable for QoS control and SLS auditing, as it provides valuable inputs for the underlying traffic control mechanisms.

Active monitoring has been matter of research over the past few years [3–8], however, extending its study to a multi-class network paradigm is crucial and still needs to be covered. Given the distinct treatment each service class and corresponding traffic aggregate receives, multi-class networks introduce new dimensions on active monitoring as probing traffic needs to be in-band and adjusted to each class measuring requirements, with minor resource consumption. To be useful for QoS-aware traffic control mechanisms operating on short or medium timescales, the probing process should provide accurate, fast and continuous measures of each class performance without causing noticeable side-effects on the class real traffic. To reduce intrusion, a single probing pattern should be able to capture simultaneously multiple QoS metrics of a class.

These aspects raise important questions: How to extend the monitoring process to a multi-class network environment? Can a given pattern capture correctly more than one metric, according to the service characteristics? How often should such process take place to capture the network dynamics, without contributing significantly to the network load? The present work aims to find answers to these questions, studying different characteristics of probing patterns for the estimation of IPTD, ipdv and IPLR metrics, commonly identified for measuring quality and performance of Internet services [9–12]. As a case study, we consider a multi-class domain where a distributed monitoring-based admission control (AC) model [13, 14] dynamically controls traffic entering the domain. This service-oriented AC model resorts to edge-to-edge on-line monitoring to obtain measures reflecting each class performance and to guide AC decisions. Therefore, this scenario is particularly suitable for studying active monitoring on a per class basis.

This paper is structured as follows: the problematic of multi-class QoS monitoring and the identification of relevant QoS metrics is debated in Section 2; the description of the AC model including its operation and implementation details are summarised in Section 3. Section 4 is devoted to the discussion of tuning the active monitoring process and corresponding results, while Section 5 includes the main conclusions of the work.

2 Multi-class Active Monitoring

Active monitoring is a measurement methodology which resorts to intrusive traffic (probes) specifically injected in the network for measurement purposes. This methodology allows to emulate a wide range of measurement scenarios, providing a straightforward way to check QoS and SLS objectives. Probing also brings an additional advantage when measuring edge-to-edge QoS and performance. As specific packets are injected in the network containing timestamping and sequencing data, delay and loss estimation is simplified. Note that, obtaining these estimates combining link-by-link measures is not an efficient and easy solution [15]. For these reasons, active measurement techniques are particularly suitable for edge-to-edge on-line QoS monitoring purposes, providing feedback to short or medium term network management and traffic control mechanisms, i.e. the monitoring outcome is used to drive reactive mechanisms (see Fig. 1). Currently, with the advent of QoS networks and SLS establishment, on-line monitoring is also required to provide up-to-date information of network performance to customers and providers.

Multi-class networks pose additional challenges on on-line active monitoring. As each traffic aggregate receives a distinct treatment, either from a node [16, 17] or a domain perspective [18], probing needs to be carried out in a per-class basis (in-band) so that class measuring requirements and behaviour are met and sensed. Being an intrusive process, probing in high priority classes may take over resources needed by real traffic not only in those classes but also in low priority classes. Therefore, special concern is needed when defining the probing pattern characteristics [15].

Specially in multi-class environments, an efficient on-line monitoring should be an accurate, fast, continuous, low-overhead and low-interfering process. While accurate and fast measurements allow a correct assessment of the current network state providing up-to-date information, systematic measurements allow to auto-correct the measures and sense each traffic class dynamics. Additionally, the overhead and interference introduced by probes, should be minimized to avoid degrading the class QoS, e.g. decreasing the throughput or causing persistent loss or delay. To minimize probing impact a single probing pattern should sense simultaneously multiple QoS metrics of a class.

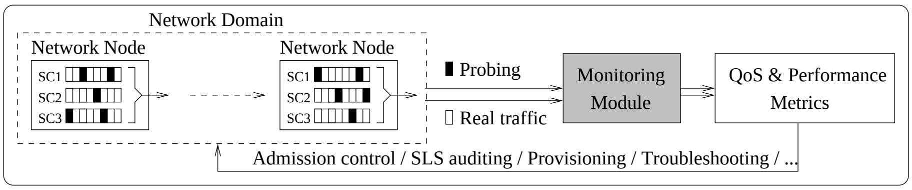

Fig. 1. Multi-class active monitoring

2.1 Controlled QoS Metrics

The definition of relevant metrics to control and measurement methodologies to apply have been matter of research in the last few years. In particular, IETF IPPM and ITU-T work on QoS in IP networks have devoted substantial efforts to this topic [12, 19, 20] and some ongoing projects and operational environments use its outcome (e.g. Surveyor [21] and RIPE[3]). From these works it is noticeable that one-way metrics have received particular attention and preference over two-way metrics. In fact, due to possible asymmetric paths and/or different network resource allocation and queuing behaviour in both directions, one-way measurements give more precise information and are, therefore, more useful.

In this paper we focus on capturing simultaneously the behaviour of three relevant one-way metrics [9–11], the IP Packet Transfer Delay (IPTD), IP Packet Delay Variation (ipdv) and IP Packet Loss Ratio (IPLR) metric, in a dynamically loaded and controlled multi-service environment (see Section 3). These metrics are defined in Table1 considering a measuring time interval of Δt_i. The mean value of each metric in Δt_i, measured for a ingress-egress pair and traffic class i, is controlled by the AC module as described in Section 3.1.

Table 1. Controlled QoS metrics

IP Transfer Delay ($IPTD$)	$IPTD_{i,pkt} = (t_{E_m,pkt} - t_{I_n,pkt})$
Mean IPTD ($\overline{IPTD}$)	$\overline{IPTD}_{i,\Delta t_i} = (\sum IPTD_{i,pkt} / \sum pkts\_recv_i)_{\Delta t_i}$
Inst. Packet Delay Var. ($ipdv$)	$ipdv_{i,2pkt} = (IPTD_{i,pkt} - IPTD_{i,pkt-1})$
Mean ipdv ($\overline{ipdv}$)	$\overline{ipdv}_{i,\Delta t_i} = (\sum ipdv_{i,2pkt} / \sum pkts\_recv_i)_{\Delta t_i}$
IP Loss Ratio (IPLR)	$IPLR_{i,tot} = tot\_pkts\_lost_i / tot\_pkts\_sent_i$
Mean IPLR ($\overline{IPLR}$)	$\overline{IPLR}_{i,\Delta t_i} = (\sum pkts\_lost_i / \sum pkts\_sent_i)_{\Delta t_i}$

3 Multi-service Networks with Monitoring-based AC: A Case Study

As mentioned before, active monitoring, among other purposes, can provide valuable inputs for managing network traffic control tasks and related policies. Here, to access the effectiveness of the proposed probing approach, a service-oriented monitoring-based AC model [13, 14] for multi-service class-based networks is used as a case study. In order to better understand the testing scenarios and the platform where the active measurements are carried out, we briefly summarise this model.

3.1 AC Model Description

The AC model resorts to edge-to-edge on-line monitoring to obtain adequate feedback of each class behaviour and performance so that proper AC decisions can be taken. To dynamically control traffic entering the network, the model underlying AC rules control both QoS levels in a network domain and the sharing of active SLS between domains. While ingress routers perform explicit or implicit AC depending on the application type and corresponding traffic class, egress routers perform on-line QoS monitoring and SLS control. *On-line QoS Monitoring*, carried out on an ingress-egress basis, measures specific metrics for each service type. The obtained measures reflect a quantitative view of the service level available from each ingress node. *SLS Control* monitors the usage of downstream SLSs at each egress node so that traffic to other domains does not exceed the negotiated profiles. QoS monitoring statistics, SLS utilisation and associated parameters are then sent to the corresponding ingress routers to update an Ingress-Egress service matrix used for distributed AC and active service management. This notification is carried out periodically, when a metric value or its variation exceeds a limit or the SLS utilisation exceeds a safety threshold.

Assuming I as a set of N ingress nodes, i.e. $I = \{I_1, I_2, ..., I_N\}$ and E as a set of M egress nodes, i.e. $E = \{E_1, E_2, ..., E_M\}$ in domain D, the admission criterion applies rules for: 1. Rate-based SLS control and 2. Class QoS control:

1. For each ingress node $I_r \in I$ with $1 \leq r \leq N$, a new flow is admitted for class i if

   $$\rho_s + r_j \leq \beta_s R_s \qquad (1) \qquad\qquad \rho_s = \sum_{k=1}^{N} \rho_{i,k} \qquad (2)$$

   where ρ_s is the current measured load or estimated rate of flows using SLS_s, r_j is the rate specified for flow j, $0 < \beta_s \leq 1$ is the utilisation target for the SLS and R_s is the rate defined in SLS_s.
2. A new flow is accepted or rejected depending on the value of an acceptance status variable in Δt_i. This variable, updated by checking the controlled parameters $P_i = \{p_1, p_2, ..., p_p\}$ of class i against the corresponding pre-defined threshold t_p (see Eq.(3)) affected by a safety margin to the parameter bound (see Eq.(4)), is kept unchanged during Δt_i. $\tilde{p}_p$ represents the measured value of p_p for Δt_i.

   $$\forall p \in P_i : \tilde{p}_p \leq t_p \qquad (3) \qquad\qquad t_p = \beta_p p_p \qquad (4)$$

More details on the AC model including its end-to-end operation are given in [8, 14].

3.2 Model Implementation and Test Platform

The test platform consists of a network simulation prototype (see Fig. 2), developed in the Network Simulator (NS-2), supporting three service classes: SC1, oriented to UDP streaming applications with hard real-time constraints, provides a high quality service guarantee. SC2, oriented to a range of UDP streaming applications with soft real-time constraints, provides a predictive service with low delay, low loss and minimum bandwidth guarantee. SC3, oriented to adaptive TCP applications, provides the common best-effort service. There is also the possibility of injecting concurrent traffic (CT-I2) of any of the above classes to allow testing the effect of cross-traffic on probing.

The corresponding service-dependent AC rules are parameterised as specified in Table 2[1]. As initial configuration, we have considered three downstream SLS, one per service class. The choice of SLS rate shares (R_s), safety margins (β_s) and QoS parameters thresholds (t_p) are defined in the right side of

[1] This AC model configuration allows the occurrence of possible QoS degradation or service disruption which is useful to verify if probing is able to detect it.

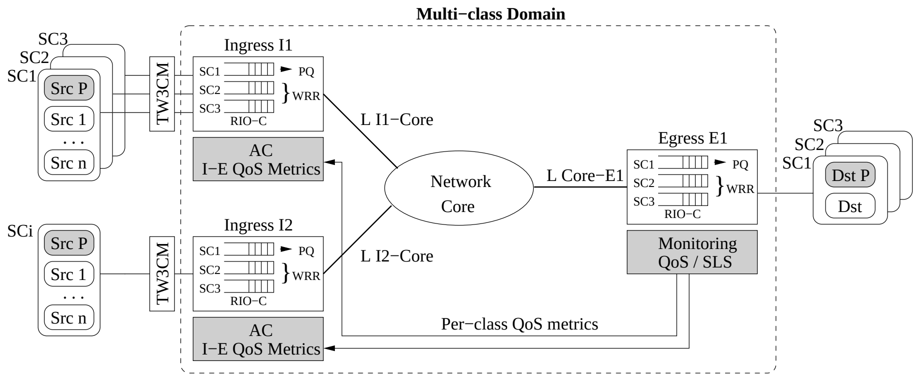

Fig. 2. Network simulation topology

Table 2. As shown, larger safety margins and tighter QoS parameter thresholds have been defined for more demanding classes. The AC thresholds are set taking into account the domain topology dimensioning, queuing and propagation delays and perceived QoS upper bounds for common applications and services [22–24].

The routers implement the three traffic classes defined above according to an hybrid Priority Queuing - Weighted Round Robin (PQ-WRR(2,1)) scheduling discipline, with RIO-C for active queue management. Each class queue is 150 packets long. The domain internodal link capacity is 34Mbps, with a 15ms propagation delay. At network entrance, each traffic class is policed and marked using a TSW3CM and the access links to domain boundaries have been configured so that intra-domain measurements are not affected. For the defined classes SC1, SC2 and SC3 three types of sources - Constant Bit Rate (CBR) sources, Exponential on-off (EXP) and Pareto on-off (PAR) were considered. Most of the results included in Section 4 use EXP sources with on-off intervals of 500ms-500ms and a peak rate depending on each class. Generically, SC1 comprises UDP traffic with small to medium peak rate (300kbps) and packet sizes (128bytes). SC2 and SC3 comprises UDP traffic with higher peak rate (1Mbps) and packet sizes (512bytes). The flow arrival process is Poisson with exponentially distributed interarrival and holding times of 500ms and 60-120s, respectively. Concurrent traffic injected at Ingress I2 is mapped to class SC1.

Table 2. SLS and QoS control configuration

SLS Control Rule: $\rho_s + r_j \leq \beta_s R_s$				
Class	Monitoring Inputs ρ_s	Flow Inputs r_j	SLS Rate R_s (% Class share)	Safety Margin β_s
SC1	Traffic load	peak rate	3.4Mbps (10%)	0.75
SC2	Traffic load	mean rate	17.0Mbps (50%)	0.90
SC3	Traffic load	n.a.	13.6Mbps (40%)	1.0

QoS Control Rule: $\forall p \in P_i : \tilde{p}_p \leq t_p$			
Class	Monitoring Inputs $\tilde{p}_p$	Flow Inputs	QoS Param. Thresh. t_p
SC1	IPTD, ipdv, IPLR	if available	$35ms; 1ms; 10^{-4}$
SC2	IPTD, IPLR	if available	$50ms; n.a.; 10^{-3}$
SC3	IPLR	n.a.	$n.a.; n.a.; 10^{-1}$

4 Tuning the Multi-class Active Monitoring Process

Ideally, probing should be able to reflect both the shape and the scale of each service metric so that the class behaviour can be correctly captured, with reduced intrusion. If this is accomplished, probing can provide valuable inputs both for SLS auditing in the domain and for active network control, such as AC. The main objective of our study is to determine and tune adequate probing streams for controlling the multiple QoS parameters of each service class. To pursue this objective, probing is studied as regards its distribution, rate and drop precedence (colour) in case of queue congestion. This novel approach of colouring probes aims at exploring active queue management actions in case of congestion and different probabilities of packets reaching the network boundary. To assess the suitability and effectiveness of probing for the QoS parameters in Table 2, the probing measurement outcome is cross-checked against the corresponding measures using the real traffic in each class, i.e. active and passive measurements results are compared. This verification process is based on a direct comparison of graphical results and statistical analysis of collected measurement samples, for the different QoS parameters and service classes.

4.1 Matching IPTD, ipdv and IPLR

Common probing patterns for systematic measurement include Poisson traffic with light probing rates, e.g. 2 or 4 pkts/s [3, 21], aiming at obtaining multiple QoS metrics estimation. In order to increase the chance of probing packets getting to the network boundary, we use high precedence (green) marked probes. This would refrain the network to discard them in presence of congestion. The obtained QoS measures for classes SC1, SC2, SC3[2], when an in-band Poisson probing pattern of 2 pkts/s (of 100bytes each) is used[3], are depicted in Fig. 3. As illustrated, probing is able to capture closely the shape and scale of IPTD, even small peak variations. However, ipdv and IPLR are not sensed and measured properly. As shown, ipdv has a clear mismatch in scale. As ipdv is a consecutive packet measure, probing gaps lead to higher measures as consequence of queue occupancy variations. For IPLR, unless heavy loss occurs, green probes did not detect the full class behaviour. These results suggest the use of alternative probing patterns with higher rates and/or low precedence (red) packets in order to increase sensitivity to loss events, as low precedence packets are the first to be discarded when network congestion increases. Intuitively, increasing the rate would also allow a better match for ipdv as probing gaps are reduced, however, the overhead introduced needs to be taken into account.

Probing rates impact In this test scenario, we have considered a probing rate ranging from 1.6kbps (2 pkts/s, 100bytes) to 12.8kbps with power of two increases, keeping a measurement interval $\Delta t = 5s$. For the number of classes considered, this corresponds, in the worst case, to an approximate accumulate probing rate of 0.1% of the bottleneck link capacity (34Mbps) per ingress-egress pair. Although this value is not significant as a whole, for classes with low bandwidth share and high priority treatment such as SC1, this may be relevant when considering multiple ingress-egress pairs ($O(n * m)$).

[2] Although the metrics for AC are service dependent and defined according to Table 2, to obtain a more encompassing view of probing results, both IPTD, ipdv and IPLR metrics are evaluated for the three classes in use.

[3] As regards the choice of a probing distribution, apart from Poisson both periodic and exponential on-off patterns were also tested. We have noticed that, for these probing distributions the metrics' behaviour and their trends are equivalent. Despite this, to avoid possible synchronisation effects yielding to unbiased samples, in real environments the Poisson distribution is recommended [19] and, therefore, it is used in the current tests.

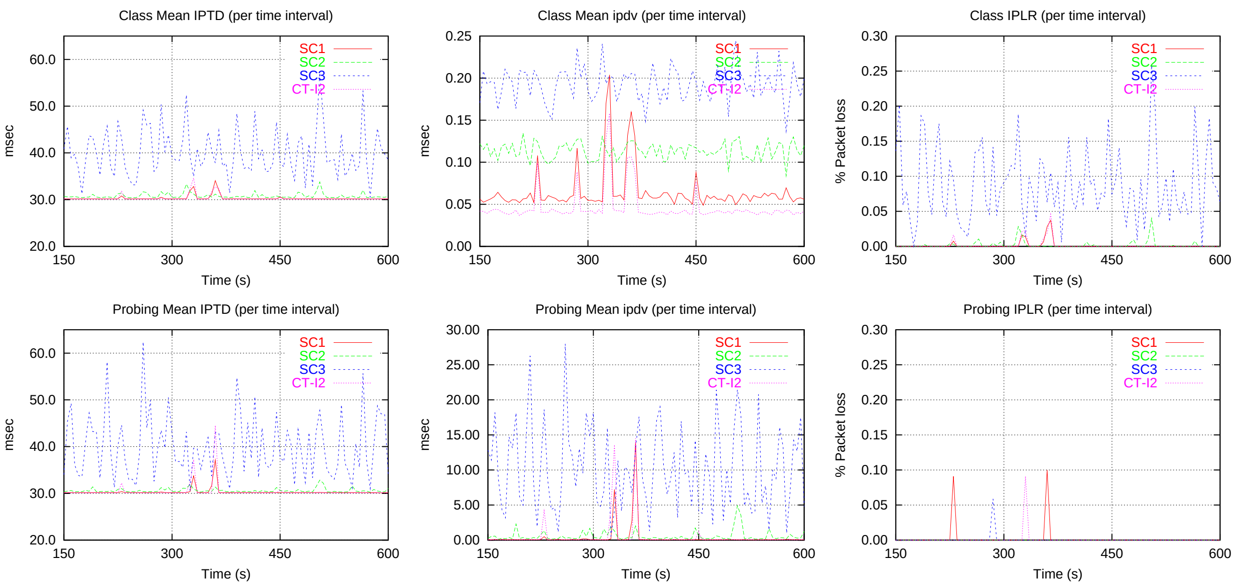

Fig. 3. Comparing class and probing measures (2 green pkts/s and $\Delta t = 5s$)

The obtained results show that: (i) for IPTD, a small probing rate of two green pkts/s is enough to achieve a close match of the metric behaviour; (ii) ipdv scale is difficult to obtain regardless the test probing rates and small class ipdv variations are magnified by probing in one order of magnitude, approximately. Only when the queues remain in a reasonable steady state, under moderate load (%70), ipdv is more closely measured (see example in Fig. 4 (a)). As increasing probing rates, consequently decreasing the inter-packet gaps, is not always enough, specially on SC3, the ipdv mismatch under different rates suggests that queuing delay oscillations may still persist across multiple time scales; (iii) the probing rates considered, with green packets, were unable to capture IPLR properly in both shape and scale. Fig. 4 (b) exemplifies the overall and per class network utilisation considered in these and the tests below

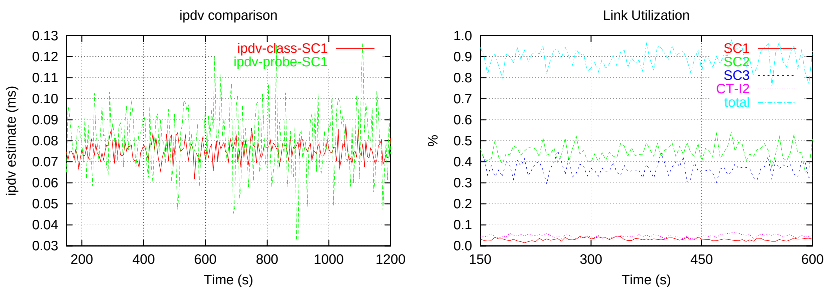

Fig. 4. (a) Comparing ipdv for SC1 (Δt=5s; 4pkts/s) (b) Network utilisation

Probing drop precedence impact An important finding is that, changing the drop precedence of probing packets to low (red) brings a significant improvement in IPLR estimation results. As Fig. 5(a) shows, a probing rate of 4 red pkts/s can sense most of loss events following the shape of the distribution but missing the correct scale, independently of the test probing rate. Although, red probing traffic is good for assessing IPLR, IPTD scale is slightly affected as previously high delayed packets are now mostly discarded. Once again, increasing the probing rate does not remove this side-effect completely. Fig. 5(b) shows the IPTD and IPLR dispersion when comparing class and probing estimation, for a probing rate of 12.8kbps. As illustrated for SC2, IPTD is under-estimated, and IPLR, despite including most of loss events, maintains a scale deficit. The scale error in IPLR estimation is justified by the huge difference between the total number of probes and class packets, which is difficult to overcome due to probing overhead limitations.

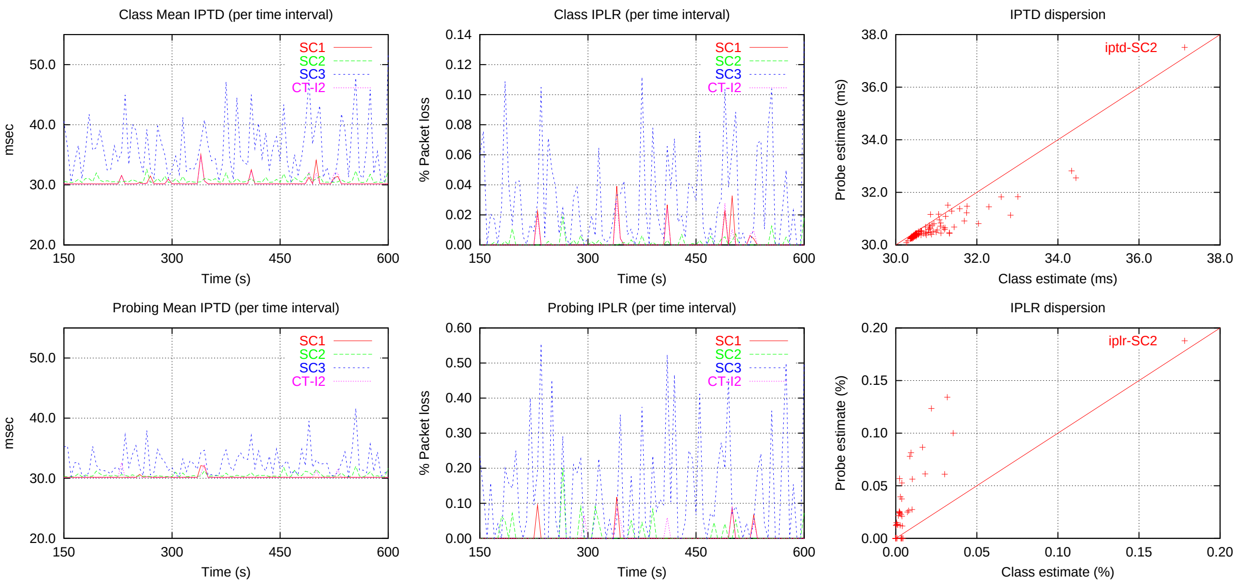

Fig. 5. (a) Comparing class and probing measures (b) Dispersion for a probing rate of 12.8kbps

In summary, the initial results indicate that a low precedence in-band rate of 3.2kbps (4 pkts/s) allows a good compromise between capturing multiple metrics and introduced overhead, specially under moderate load conditions. In order to quantify the significance of graphical results, Table 3 includes several statistics aiming to compare, infer and correlate probing and class measurement outcome, for the different service classes. According to these results, SC3 exhibits the higher probing estimation errors for the three metrics considered. This is due to heavy queue occupancy fluctuations and probing loss resulting from a more relaxed AC and low priority treatment this class suffers.

Current tests for capturing ipdv include the use of back-to-back probing packets. Using interleaved colour (green, red) probes to capture IPLR without degrading IPTD scale is also under study. Depending on the overall purpose of the metrics and traffic control mechanisms which may react based on them, a viable solution to overcome excessive sensitivity to fluctuations and mis-scaling of the metrics behaviour is to increase the time interval Δt in which measurements are carried out. A wider Δt will allow a more stable measurement interval as traffic variability is smoothed and more probing packets are taken into account in a single measure.

Table 3. Statistics of probe and class metrics for service classes SC1, SC2 and SC3

	SC1						SC2						SC3					
	IPTD (ms)		ipdv (ms)		IPLR (%)		IPTD (ms)		ipdv (ms)		IPLR (%)		IPTD (ms)		ipdv (ms)		IPLR (%)	
Stats.	Class	Probe	Class	Probe	Class	Probe	Class	Probe	Class	Probe	Class	Probe	Class	Probe	Class	Probe	Class	Probe
mean	30.3	30.2	0.07	0.09	0.0015	0.0048	30.7	30.5	0.12	0.45	0.0013	0.0037	36.2	31.9	0.18	2.49	0.029	0.129
std.dev.	0.62	0.14	0.03	0.02	0.0071	0.0244	0.49	0.45	0.01	0.47	0.0031	0.0152	4.71	1.53	0.03	2.15	0.032	0.130
P 2.5	30.2	30.1	0.05	0.04	0	0	30.4	30.2	0.09	0.15	0	0	30.5	30.3	0.13	0.23	0	0
1st Q	30.2	30.2	0.06	0.06	0	0	30.4	30.3	0.10	0.21	0	0	32.5	30.7	0.16	0.74	0.005	0
2nd Q	30.2	30,2	0.06	0.07	0	0	30.5	30.4	0.11	0.26	0	0	34.9	31.6	0.18	2.10	0.020	0.091
3rd Q	30.2	30.2	0.07	0.08	0	0	30.8	30.5	0.12	0.49	0.0003	0	38.2	32.8	0.20	3.59	0.039	0.2
P 97.5	32.1	30.2	0.17	0.15	0.076	0.032	32.1	31.8	0.13	1.70	0.012	0.050	48.1	35.7	0.23	8.87	0.125	0.462
corr.	0.81		0.62		0.75		0.79		0.61		0.78		0.69		0.62		0.86	
mean $\overline{\epsilon}$	0.154		0.031		0.0044		0.265		0.336		0.0038		4.230		2.310		0.103	
#bin	211		211		211		211		211		211		211		211		211	

5 Conclusions

This paper has studied the use of active monitoring to control multiple QoS parameters in multi-service class-based IP networks. Active monitoring in these networks is a particular challenge as probing needs to be in-band to capture each class behaviour, while reducing overhead and intrusion side-effects. This motivates the use of light probing streams able to sense simultaneously the behaviour of multiple QoS metrics of each class. Taking a multi-class domain with monitoring-based admission control as a case study, we have explored several aspects of probing patterns and their ability to capture IPTD, ipdv and IPLR related metrics. Comparing probing and real traffic measurements, our results show that IPTD can be easily captured for very low probing rates, however, ipdv and IPLR scale and shape are not easy to match. ipdv is a rather sensitive metric to class priority treatment and load conditions, being more difficult to capture when queues experience heavy fluctuations. As regards IPLR, we have found that exploring the action of active queue management mechanisms on packet drop precedences can significantly influence the probing measurement outcome. For instance, while low drop precedence probes are suitable for IPTD estimation, most of the class IPLR events are missed and, consequently, the metric shape and scale are not captured. We have showed that high drop precedence probing packets strongly improves IPLR estimation, without impairing IPTD estimation significantly, while keeping the probing rate as low as 4 pkts/s. Ongoing tests concentrate on further tuning in-band probing patterns and on exploring specific techniques for improving multiple QoS metrics estimation.

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