ESTIMATION OF THE DISTRIBUTIONS OF THE QOS PARAMETERS USING SAMPLED PASSIVE MEASUREMENTS TECHNIQUES

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Abstract: As networks grow in complexity and scale, the importance of network performance monitoring and measurement also increases significantly. High data rates often lead to large amount of measurement results. Therefore, in order to prevent an exhaustion of the network resources and to reduce the measurement cost, a reduction of the collected data is required. A performance measurement method for estimating the actual network performance, experienced by the user, has been proposed. This study focuses on monitoring the network performance and estimates its main Quality of Service (QoS) parameters (delay, throughput, and jitter) through the use of a non-intrusive passive measurement method based on sampling methodologies. This method will overcome the drawbacks of both active and passive monitoring methods. That is because it measures the actual performance experienced by the user and requires reduced calculations of QoS parameters from the sampled packets. The validation of this approach was analysed and verified through simulations. Three different sampling techniques (systematic, random, and stratified) were investigated. The study indicated that an accurate estimation of the QoS parameters could be obtained without the need to measure across the whole packets of traffic information. As a result, the scheme has shown an estimation of the detailed characteristics of performance for each user. For a bottleneck based network topology and traffic conditions used, the random sampling showed the best overall performance.

1 INTRODUCTION

Quality of Service (QoS) network measurement and analysis have long been of interest to the networking research community. The analysis of network QoS is based on measuring the network dynamic parameters to provide some insight into the way the user traffic is treated within the network. Monitoring and measurement schemes usually fall into two categories: passive and active methods. A passive measurement is based on achieving measurement of the actual traffic load in the network. This category often needs the storage and processing of very large amount of data. An active measurement, on the other hand, is based on generating (probing) a new traffic to be used to get the measurements statistics. In this case, the QoS and performance of the probe-packet stream, which is sent periodically, is monitored to determine (infer) the QoS and the performance of the user's packets and the network directly. Many active monitoring tools have been developed to monitor the network performance (CAIDA, 2005).

When using an active method, the probe packets will perturb the network. In addition to that, sometimes the measurements of the probing packets do not represent the actual user measurements (Aida *et al*., 2002). Passive measurements have the advantage of not adding an extra load to the network. However, they require the transfer of the captured data for comparison with the other data and the identification of each packet by its header or content, which is hard when the data volume is huge. Therefore, passive measurements have the disadvantage of requiring substantial resources for comparison and computation (Ishibashi *et al.,* 2004).

A combination of both active and passive methods could be employed for performance measurement. A performance measurement method, Change-of-Measure based Passive/Active Monitoring (CoMPACT Monitor), was used for

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estimating the actual network performance experienced by users (Aida *et al*., 2002 and Ishibashi *et al.,* 2004).

In order to overcome some of the disadvantages of both active and passive schemes, sampling methodologies can be employed. Using these methodologies for the passive method will reduce the amount of data to be processed, reduce the demand on the overhead processing time of the collected data, and hence speed up the performance measurement results. In addition, there is no need for artificial traffic to be injected which will perturb the network and bias the measurements as in the active method.

Sometimes, the estimation of the network or user performance may be difficult to be obtained from direct measurements of the whole traffic. In this paper, a scalable and efficient measurement approach has been used to estimate the network performance experienced by users and it has been used to estimate the dynamic QoS parameters (delay, throughout and jitter). The approach is based on a combination of a sampling technique and passive monitoring method. It can estimate not only the actual performance of individual users and applications but also the mixed performance experienced by these users. The estimation of mixed users performance will be one of the issues raised in future work of this study.

This rest of this paper is organised as follows: Section 2 details the theory behind the sampling techniques. Section 3 details the mathematical model of the proposed approach. Section 4 presents the measurement approach used to validate the proposed approach. Section 5 illustrates the experimental results produced. Section 6 is the conclusion.

2 SAMPLING TECHNIQUES

The use of sampling techniques provides information about a specific characteristic of the traffic. Sampling methods can be characterised by the sampling algorithm used, the trigger type (i.e. count-based or time-based trigger) for starting a sampling interval and the length of the sampling interval (Zseby, 2002):

1- Sampling algorithm: this describes the basic procedure for the process of samples selection. There are three basic processes: systematic sampling, random sampling, and stratified sampling.

a) Systematic sampling: It describes the procedure of selecting the starting point and the frequency of the sampling according to a pre-determined function. This includes for example the periodic selection of every n^{th} element of a trace. Figure 1 shows the schematic of the systematic sampling (Claffy *et al*., 1993).

Figure 1: Schematic of systematic sampling.

b) Stratified sampling: This method splits the sampling process into multi-steps. First, the elements (packets) of the parent population are grouped into subsets in accordance to a given characteristics. Then samples are randomly taken from each subset. Figure 2 illustrates the schematic of the stratified sampling [5]. For example, if the whole region of interest, *A*, is spilt into *M* disjoint sub-regions (i.e. buckets) such that (Bohdanowicz and Weber, 2005):

$$A=\bigcup_{k=1}^{M} A_k \quad with\ A_j \cap A_l = 0\ \ for\ \ l \neq j \qquad (1)$$

$$where A_k\ is\ the\ k^{th}\ sub\text{–}region$$

Figure 2: Schematic of stratified sampling

c) Random sampling: Random sampling selects the starting points of the sampling interval in accordance to a random process [4]. The selections of sampled elements are independent and each element has an equal probability of being selected. Figure 3 depicts the schematic of the random sampling (Claffy *et al*., 1993).

Figure 3: Schematic of random sampling

2- Sampling frequency and interval length: Sampling techniques can be differentiated by the event that triggers the sampling process (Zseby, 2002, Claffy *et al*., 1993 and Bohdanowicz and Weber, 2005). The trigger determines what kind of event starts and stops the sampling intervals. With this, the sampling frequency and the length of the sampling interval (measured in packets arrived or elapsed time) are determined.

3 THE ESTIMATION CONCEPT

This method was used in (Aida *et al*., 2002 and Ishibashi *et al.,* 2004) to estimate the actual delay experienced by a network user and by mixed applications based on active measurement using a change-of-measure framework. By change-of-measure framework, the authors meant a framework in which the measure of network performance for probe packets can be converted to a measure for user packets. In this paper, the concept of this method will be used to estimate QoS parameters but based on a combination of passive measurement and sampling techniques. The mathematical approach will be modified to include the sampling technique.

Suppose a network under consideration is shared by K users and let $X_k(n)$ denotes the measurement objective of the *nth* packet of user k. X has the distribution function of P. The distribution of X may be written as:

$$\Pr(X > a) = \int 1_{\{x>a\}} dP(x) = E_P\left[1_{\{X>a\}}\right] \quad (2)$$

where (a) is an arbitrary real number, E[.] is the expected value and $1_{\{.\}}$ denotes the indicator function:

$$1_{\{x \rangle a\}} = \begin{cases} 1 & if \;\; x > a \\ 0 & otherwise \end{cases} \quad (3)$$

If there are n packets arrived in a measurement period, $X(i)$ denotes the i^{th} value of X. Then the estimator $Z_X(n,a)$ of the distribution of X, which is like the mean estimator, is given by:

$$Z_X(n,a) = \frac{1}{n}\sum_{i=1}^{n} 1_{\{X(i)>a\}} \quad (4)$$

Suppose a situation in which it is difficult to measure the user traffic directly and an estimate of its distribution cannot be obtained. Let $V(t)$ be the network performance at time t such that if the i-th arrival packet occurs at t_i; then $V(t_i) = X(t_i)$. Also, let Y be the sampled version of $V(t)$, and let the distribution function of Y be Q. Thus, Y is considered the network performance as measured by sampled packets and the distribution of Y to estimate the distribution of X. The distribution of X can be rewritten by using a change of measure based on the distribution of Y as follows:

$$\Pr(Y > a) = \int 1_{\{Y>a\}} dP(y) \cong \Pr(X > a)\text{; } then,$$

$$\Pr(X > a) \cong \int 1_{\{y>a\}} \frac{dP(y)}{dQ(y)} dQ(y) = E_Q\left[1_{\{Y>a\}} \frac{dP(Y)}{dQ(Y)}\right] \quad (5)$$

Now, suppose n user- packets are sent and Y packets are measured (sampled) m times. Let $Y(j)$ be the j-th measurement sample at s_j such that $Y(j) = V(s_j)$, $j=1,2,3...m$. Then an estimator $Z(m,a)$ of $Pr(X>a)$ can be derived by using $Y(j)$ as follows:

$$\Pr(X > a) \cong E_Q\left[1_{\{Y>a\}} \frac{dP(Y)}{dQ(Y)}\right] = \frac{1}{m}\sum_{j=1}^{m} 1_{\{Y>a\}} \frac{dP(Y)}{dQ(Y)} = Z_Y(m,a), \;\; So,$$

$$Z_Y(m,a) = \frac{1}{m}\sum_{i=1}^{m} 1_{\{Y(j)>a\}} L(j) \quad (6)$$

$$where,\; L(j) = \frac{dP(Y(j))}{dQ(Y(j))}$$

$L(j)$ is the ratio between the probabilities of X and Y. It is called the likelihood ratio, which can be obtained through passive measurement, in which simply it is the count of the number of user packets arriving between the consecutive sampled packets. Let $\rho_X(t,\delta)$ be traffic volume (i.e. the number of user packets) arriving in an interval [t, $t+\delta(t)$] and let $\rho_Y(t,\delta)$ be the number of measurements (i.e. the number of sampled packets) in the interval [t, $t+\delta(t)$]. This indicates that one measurement (sample) of Y in that interval can be interpreted as $\rho_X(t,\delta)/\rho_Y(t,\delta)$. So, L can be rewritten as the ratio between the distributions of the user packets received at a given period to the distribution of the sampled packets in that period:

$$L(j,\delta) = \frac{\rho_X(s_j,\delta) \Big/ \sum_{j=1}^{m} \rho_X(s_j,\delta)}{\rho_Y(s_j,\delta) \Big/ \sum_{j=1}^{m} \rho_Y(s_j,\delta)} \quad (7)$$

Both ρ_X and ρ_Y are the number of packets at the given period. Thus the likelihood ratio can be obtained by passive measurement. Therefore, the distribution of X is estimated as:

because $\sum_{j=1}^{m} \rho_X(s_j) = n$ and $\sum_{j=1}^{m} \rho_Y(s_j) = m$ then from(7);

$$L(j,\delta) = \frac{\rho_X(s_j,\delta) \big/ n}{\rho_Y(s_j,\delta) \big/ m} \quad (8)$$

and subsitutethis in (6) Z_Y will be (9)

$$Z_Y(m,a) = \frac{1}{n}\sum_{j=1}^{m} 1_{\{Y(j)>a\}} \frac{\rho_X(s_j,\delta)}{\rho_Y(s_j,\delta)}$$

4 MEASUREMENT APPROACH

The following section describes the use of sampling techniques for measurements with two monitoring points. In this work, an evaluation of the user and network performance by measuring the user QoS parameters is carried out. A performance measurement method for estimating the actual network QoS parameter experienced by the network users has been proposed based on a sampling technique. This is based on a passive monitoring approach. The basic procedure is as follows: 1) Take a suitable number of samples of the on-going current traffic, 2) Measure the network performance based on measuring the QoS parameters (delay, jitter, and throughput) using the sampled packets, and 3) Convert the sampled user version to represent the actual performance experienced by the user packets by weighting the performance with the number of user packets arriving between the sampled packets, which is measured passively.

Some metrics require correlation and synchronisation of data packets from different monitoring points like delay. This work was based on simulation, thus correlation was only considered by recognising the packets at the second monitoring. This can be done using packet-ID recognition (Zseby *et al.,* 2003). Both, correlation and synchronisation must be considered in real network

The method described, above, was used to estimate the actual end-to-end QoS parameters. To demonstrate the application of this method, network simulator *ns2* was used (NS, 2005). Figure 4 shows the network topology used for the simulation with the same characteristics of the users as shown in Table 1. It has three pairs of source/destination hosts. Sources (*N0, N1,* and *N2*) were connected to their destinations (*N5, N6,* and *N7*), respectively, through two bottleneck routers *(N3* and *N4*), which are connected with each other via 2Mb/s link. All the estimations will be done for user1. Other simulation characteristics are as follows:

- The user's packets were generated by ON-OFF negative exponential source. ON-OFF means that the packets are either sent at full rate with constant burst rate during the "ON" period or not at all during the OFF period. For these simulations, the mean ON duration is set to 1 second and the mean OFF duration is set to 5 seconds with selected packet sizes and generation rates for each application as shown in Table 1.
- The transport protocol was UDP protocol.
- Simulation time was 100 seconds.

Table (1): User's Characteristics

User	Packet Size [byte]	Generation Rate [Mbps]
1 (*N0*)	600	1
2 (*N1*)	900	1.2
3 (*N2*)	800	1.2

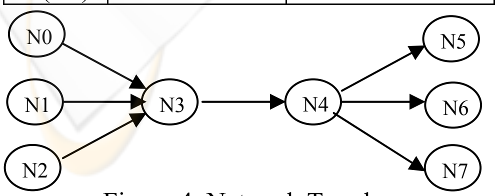


Figure 4: Network Topology

Let X_k be the actual user QoS parameter to be estimated and Y_j is the measured parameter using the sampled packets. The number of packets for user k arriving in $[s_j, s_{j+1}]$ is $\rho_k(j)$, and the number of total packets for user k is:

$$n_k = \sum_{j=1}^{m} \rho_k(j) \tag{10}$$

Then because there are one sampled packet in the period $[s_j, s_{j+1}]$ and ρ_k user packets during that period, and substituting this in equation (8), the likelihood ratio will be:

$$L_k(j) = \rho_k(j)\frac{m}{n_k} \tag{11}$$

Substituting equation (11) in equation (8), the estimate of the user parameter based upon the sampled packet is:

$$Z_y(k,m,a) = \frac{1}{n_k}\sum_{j=1}^{m} 1_{\{Y(i)>a\}}\,\rho_k(j) \tag{12}$$

Thus, by counting the number of user packets arrived between two consecutive sampled packets, the QoS parameters can be estimated. As an example, the count-based trigger frequency was 50 packets for systematic sampling and 50 buckets for stratified sampling.

5 EXPERIMENTAL RESULTS

5.1 Delay Estimation

An application of this method is to estimate the end-to-end delay for the network or for a specific user. The end-to-end delay for user1 will be estimated. Figure 5 shows the delay distributions of the actual user and an estimation of the user packet delay based on the sampled packet using equation (12). It is clear from Figure 5a that both the distribution of the sampled packet delay and that of the estimated have the same distributions. In addition, it can be seen that the minimum user delay is about 22 msec using the proposed method. This is equal to the minimum value from the actual user delay distribution, which is 22 msec. The maximum estimated delay value is about 78 msec which is very close to the value from the actual distribution which is about 80 msec. From this it can be concluded that the user delay range is between 22 and 80 msec. Therefore, in the case that it is difficult to measure the actual delay range (or the actual delay distribution); it is easy to obtain it from the estimated one.

Figures 5b and 5c depict the distributions of the measurements using the random and the stratified sampling methods. In addition, from the Figures it is obvious that the two estimation methods produce a good representation of the actual user packet delay.

They gave also the same minimum and maximum delay values as the systematic sampling for the actual user delay. In addition, in the figures there are some discrepancies between the sampled packet and the actual user estimations that is due to the number of sampled packets are small compared with the number of the user traffic packets. Also, it is clear that the discrepancies between the two distributions, using the random sampling, are less than the other sampling methodologies.

5.2 Throughput Estimation

Another application of this method is to estimate the throughput of a specific user. The end-to-end throughput of user1 will be, next, estimated.

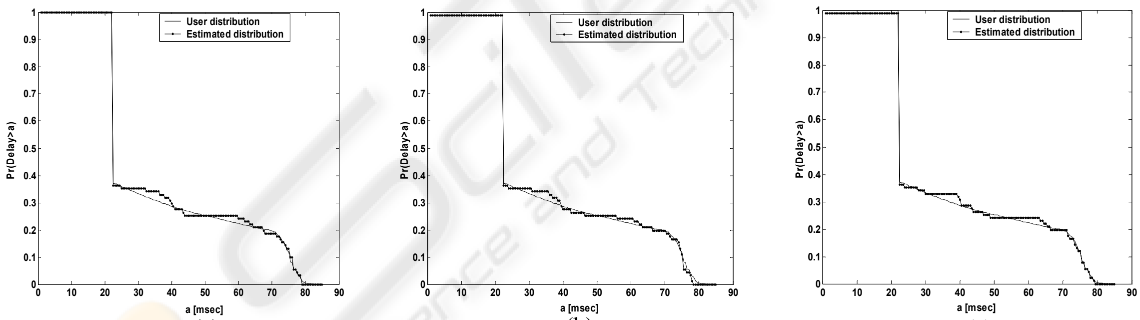
Figures 6a, 6b, and 6c illustrate the distributions of the actual user throughput and the estimated throughput using equation (12). Figures show that the sampled distribution versions produce good representations of the actual user throughput. In addition to that, all of them give an estimate of 1 Mbps of the user throughput which is the real transmission rate of the user1.

Moreover, from these figures, it can be noticed that there are some discrepancies between the actual throughput distribution and the estimated one using the systematic and stratified techniques. However, the random sampling approach produced a very accurate estimation of the actual throughput distribution compared with the other two approaches. Therefore, in cases of difficulties in measuring the maximum throughputs and in producing the estimate of actual throughput distributions of a specific traffic, this method can grant accurate measurement results.

5.3 Jitter Estimation

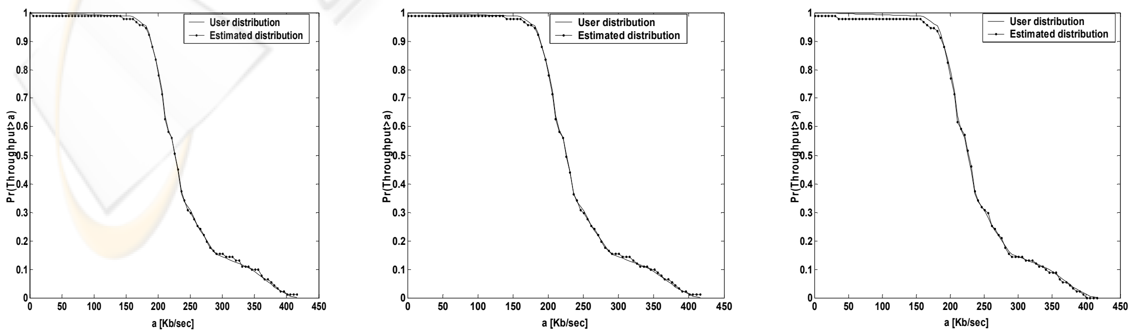
Here, the end-to-end jitter for user1 will be estimated. Figures 7a, 7b, and 7c depict the jitter distributions of the actual user packets and an estimation of the user packet jitter using the three sampling techniques using equation (12).

From these figures, it can be observed that all the distributions produced by the three sampling methods provide good illustrations of the actual user jitter. It can be seen the discrepancies are also obvious in the jitter estimation in both the systematic and stratified sampling approaches. The random sampling method produced a more accurate distribution, which stands for the actual user jitter distribution. From all distributions, it can be estimated that the minimum and the maximum jitter are 0 and 4.4msec respectively.



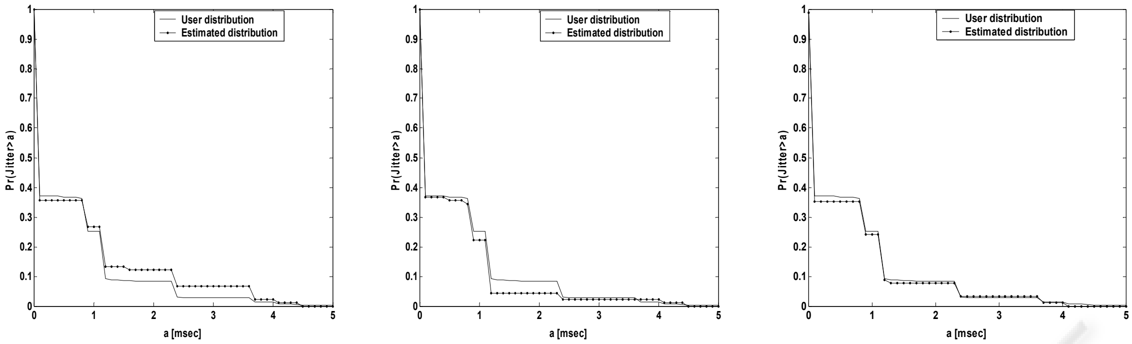
(a) (b) (c)

Figure 5: User delay and estimated user delay distributions using: (a) systematic, (b) random and (c) stratified sampling.



(a) (b) (c)

Figure 6: User throughput and estimated user throughput distributions using: (a) systematic, (b) random and (c) stratified sampling.



(a) (b) (c)

Figure 7: User jitter and estimated user jitter distributions using: (a) systematic, (b) random and (c) stratified sampling.

6 CONCLUSIONS

This work highlights the deployment of sampling techniques for estimating of QoS parameters of an ON-OFF exponential traffic. Experiments were performed with systematic, random, and stratified sampling. These methods showed how the estimation of the end-to-end QoS parameters could be achieved using two monitoring points without the necessity for calculating the whole QoS parameter population using sampling technique. Also, this method had the advantage, over the active method, of not adding an extra load to the network. In addition, unlike the passive approach, which requires the transfer and calculations of the whole traffic data.

From this study, it could be concluded that all three sampling methods provided an accurate measure of the QoS parameters. It was obvious that this method produces an acceptable estimation of QoS parameters. Nevertheless, for the network topology and traffic conditions used, the random sampling showed the best overall performance because it, randomly, selects the packets for sampling, which will represent the random conditions of the network. This could estimate not only the actual performance of individual users and applications but also the mixed performance experienced by these users. The estimation of mixed users performance will be one of the issues for future work in this study.

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