Paper presented on the 5th IFIP Workshop on Performance Modelling and Evaluation of ATM Networks, Ilkley, England, 21-23 July 1997

Leaky Bucket Analysis as a Practical Traffic Characterisation Tool

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Abstract

This paper describes a practical traffic characterisation tool, which can be used directly for ATM network design tasks. The proposed method is based on the leaky bucket algorithm which is widely used in ATM context. The goal of our characterisation method is to reveal the important properties of the traffic from practical dimensioning point of view (buffer dimensioning, shaper design, etc.) by using a fast measurement evaluation method. The usage and applicability of the Leaky Bucket Analysis method is demonstrated on various traffic sources from different applications such as Internet, video conference, and LAN-LAN interconnection. The robustness study of the Leaky Bucket Analysis method is also presented.

1 Introduction

Traffic characterisation is an important area of the broadband teletraffic research. A number of different methods have been proposed [1,2,3] and standardisation bodies also set up a list of traffic parameters that can be used for traffic characterisation [4,5]. However, this research field is living and there is still need for simple practical methods which provides important information from teletraffic engineering point of view.

We propose an easily applicable method in this paper that can be applied for given measured traffic sequences and provides the major characteristics of the traffic. The leaky bucket algorithm is well known in teletraffic theory and applied in many areas, such as traffic shaping and Usage Parameter Control. However, leaky bucket as a tool for source description is not an obvious choice, although this is the common language between the ATM terminal and the switch at the network access point setting the traffic contract [4,5]. The proposed method is based on the leaky bucket algorithm and confirms its practicability for characterisation of ATM traffic sources. It can be seen that the Leaky Bucket Analysis provides besides the standardised traffic description parameters [6] (i.e. Peak Cell Rate, Cell Delay Variation Tolerance or Sustainable Cell Rate, Burst Tolerance) other additional information which is important from traffic engineering point of view e.g. for traffic shaping [7]. The method captures directly the queuing behaviour of the traffic; therefore the Leaky Bucket Analysis is a good candidate for building up traffic models [6,8] as well.

The proposed Leaky Bucket Analysis method is described in Section 2. It is applied on different ATM cell streams captured by actual measurements in order to validate the method. Several types of single and multiplexed traffic sources from different applications (e.g. videoconference, LAN-LAN inter-connection, WWW, file transfer) are characterised by the Leaky Bucket Analysis in Section 3. Some results of our robustness evaluation of the Leaky Bucket Analysis are presented in Section 4 followed by conclusions in Section 5.

2 Leaky Bucket Analysis

2.1 The Leaky Bucket Curve

The points of the leaky bucket (LB) curve give the maximum queue length as a function of service rate in case of a G/D/1 queue fed by the source to be characterised (Figure 1). This is a monotonous decreasing curve, which has an asymptote at the mean cell rate (r_M) and approaches zero at the peak cell rate of the source (i.e. at full link rate, r_F in case of unshaped traffic). Because of the burstiness and periodicity of the traffic, the curve consists of linear sections which can be determined by their slope. There are neighbouring sections, which slopes differ with one or more orders of magnitude, and others, which have almost equal slopes. The number of section groups containing sections with similar slope is equal to the number of burst levels in the traffic. If the LB curve is plotted by post-processing of the measured ATM cell stream, it intersects the y-axis at the number of captured cells (q_N) instead of approaching infinity at the mean cell rate (Figure 1).

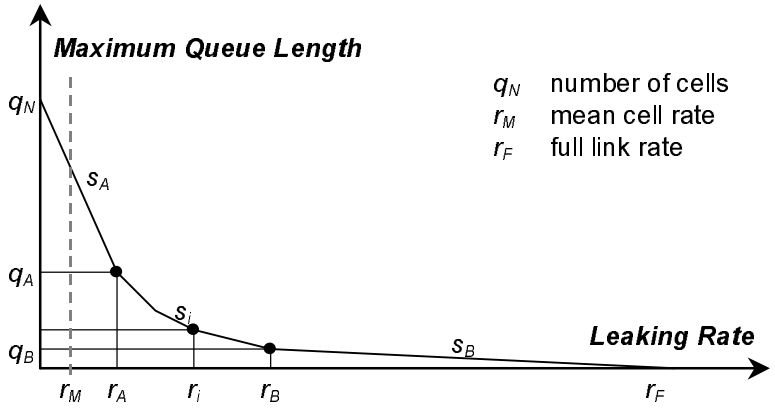

Figure 1 Measurement-Based Leaky Bucket Curve Of An Unshaped Source

Ranging from the peak rate to the mean rate, each section of the curve can be described by the following equation:

$$q(r) = q_i + (r - r_i)s_i \qquad \text{Where} \quad s_i = \frac{q_{i+1} - q_i}{r_{i+1} - r_i} \qquad \text{and} \qquad r_{i+1} < r \le r_i \qquad (1)$$

The same equation using the time period of leaking ($t = r_F / r$):

$$q(t) = q_i + \left(\frac{1}{t} - \frac{1}{t_i}\right) r_F s_i \qquad \text{Where} \quad s_i = \frac{t_i t_{i+1}(q_{i+1} - q_i)}{(t_i - t_{i+1}) r_F} \qquad \text{and} \qquad t_i \le t < t_{i+1} \qquad (2)$$

The LB curve tends to decline into straight lines close to its ends. These sections can be described in case of the measurement-based curve as follows:

$$q(t) = q_A + \left(\frac{1}{t} - \frac{1}{t_A}\right) r_F s_A \qquad \text{Where} \quad s_A = -t_A \frac{q_N - q_A}{r_F} \qquad \text{and} \qquad t_A \le t \qquad (3)$$

$$q(t) = \left(\frac{1}{t} - 1\right) r_F s_B \qquad \text{Where} \quad s_B = \left(\frac{t_B}{1 - t_B}\right) \frac{q_B}{r_F} \qquad \text{and} \qquad 1 \le t < t_B \qquad (4)$$

These equations can be used for finding the characteristic traffic parameters of the captured cell stream and calculate the slope of LB curve as a function of leaking period in order to analyse the burst structure.

2.2 The Proposed Analysis Method

The main steps of the Leaky Bucket Analysis are the following:

1. A sample trace should be captured from the investigated ATM traffic.
2. The points of the LB curve should be calculated by post-processing of captured cell stream.

3. The slope of each section should be calculated as a function of the leaking period using (2). That equation can be further simplified by a practical selection of the leaking time period (t):

$$t_i = i \quad \Rightarrow \quad s(t) = t(t+1)\frac{(q_{t+1} - q_t)}{r_F} = t(t+1)\frac{\Delta q_t}{r_F} \tag{5}$$

4. The absolute value of the $s(t)$ function should be plotted on a logarithmic scale, in order to highlight the characteristic sections of the LB curve. The value of t_A can be easily read in the LB slope graph by finding the last jump of the curve. Thus r_A can be calculated and the part of the LB curve depending on the number of captured cells can be determined.
5. Other characteristic t and related Δq_t values can be determined by finding further jumps in the $s(t)$ curve and applying (5). The related r_t–q_t pairs can be read from the LB graph and the burst size can be calculated using q_t [8].

Apart from the exploration of burst structure of the traffic, the buffer overflow probability of single sources can be estimated using the three dimensional LB Analysis method [9].

2.3 Advantages

The Leaky Bucket Analysis method can be applied on ATM cell streams captured by real measurement. Both single sources and traces from aggregate traffic (e.g. after multiplexing) can be analysed. Its main advantage is that it provides the parameters, which are considered by the access node of the ATM network. However, before the evaluation of the measurement based LB curves the untrustable parts should be detected and the important parts should be highlighted; as it is proposed in our method. A further advantage is that the LB curve characterises the traffic on each time-scale at once and in one graph, while the usual burstiness measures are time scale dependent. Moreover, the Leaky Bucket Analysis method provides a quick visual impression about the traffic.

3 Traffic Characterisation by The Leaky Bucket Analysis

Several hundreds of traces from many different ATM traffic types were captured by measurements in Telia Research, Sweden during the last couple of years [10]. These cell streams were analysed by the proposed method and some exemplary results are presented in this section in order to verify the applicability of the method.

3.1 Multiplexed CBR and VBR Traffic

Traffic of multimedia workstations connected via the Stockholm Gigabit Network was multiplexed with CBR background traffic [11]. In the range of one million cells long traces of both traffic types were captured before and after the multiplexers. LB curves of a shaped and unshaped, single multimedia sources and the aggregate traffic of four workstations are depicted in Figure 2.

The sequence (a) has lower mean cell rate, but its shape is similar to that of the other curves. It is also well pronounced that (a) intersects the x-axis much before the unshaped, single sources (b-d), i.e. its peak cell rate is definitely lower than the full link rate (r_F = 155.52 Mbps in our case). Because of these two factors this source requires much less network resources in terms of buffer and connection bandwidth, which fact is also visible in the figure. Although the background load was increased in case of (b-d) traces (see Table 1), their curves still coincide very well in both graphs. Interesting to notice that, although the aggregate traffic (e) comprises the traffic of four shaped sources, its mean rate is less than expected thanks to statistical multiplexing. The size of bursts on the first burst level around t = 10 are smaller in case of the traces of shaped sources (a,e) than for the others.

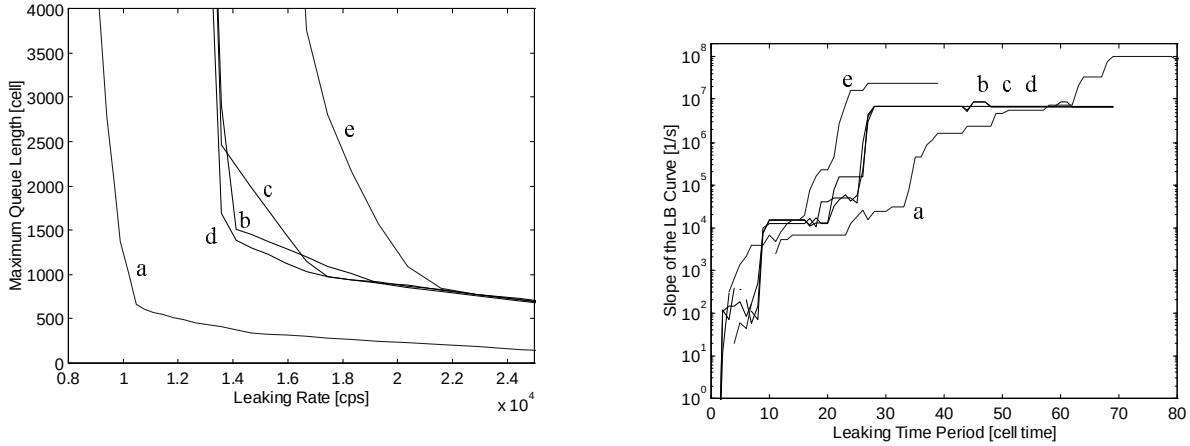

Figure 2 VBR Multimedia Sources Before And After Multiplexing
(a) before multiplexing, (b,c,d) unshaped, after multiplexing (e) aggregate of four sources

3.2 VBR Video Traffic

The effect of changing input video sequence were analysed by measuring the traffic of a TCP/IP over ATM based video conference application transferring several standardised CCIR video sequences which had equal length but different burst structure corresponding to the picture content (Figure 3). The mean cell rate and the r_A - q_A point of sequence (f), which is an almost "still picture video", are far from the other sequences. However, the LB slope curves coincide in many parts in case of each video sequence because of the similar quality settings. The number of captured cells (see Table 1) determines the s_A values.

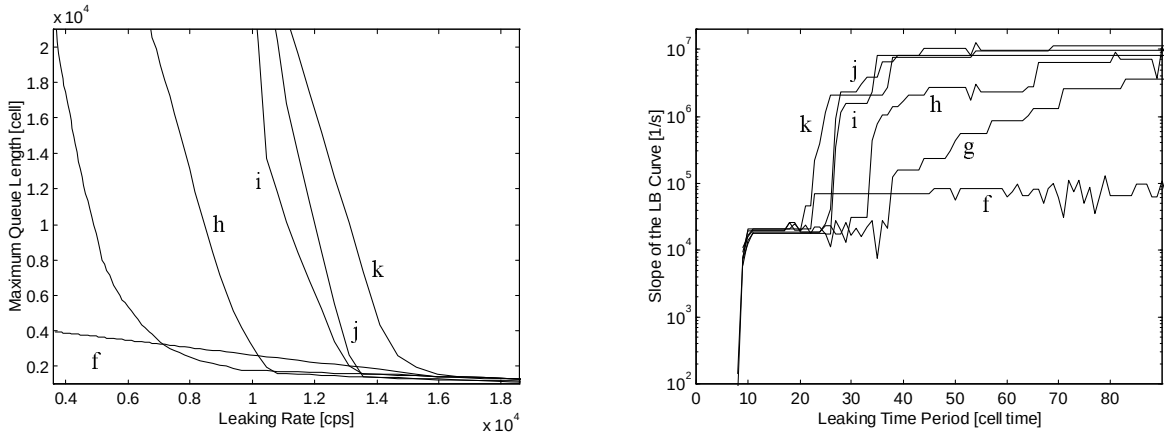

Figure 3 LB Curves Of Several Video Sequences
(f) Girl with Toys, (g) Sussie, (h) Table Tennis, (i) Tempest, (j) Flower Garden, (k) Popples

The effect of changing the frame rate as quality parameter of the video application was also investigated. It can be seen from the result in Figure 4 that the LB curves are shifted along the x-axis but the slope values are equal. The slope curves show that the burst structure is very similar in case of each captured VBR video cell stream. There are busts of smaller size, corresponding to the IP packets and others of larger size, corresponding to the video frames. The two levels are expressed by two significant jumps followed by a horizontal part in the LB slope graph.

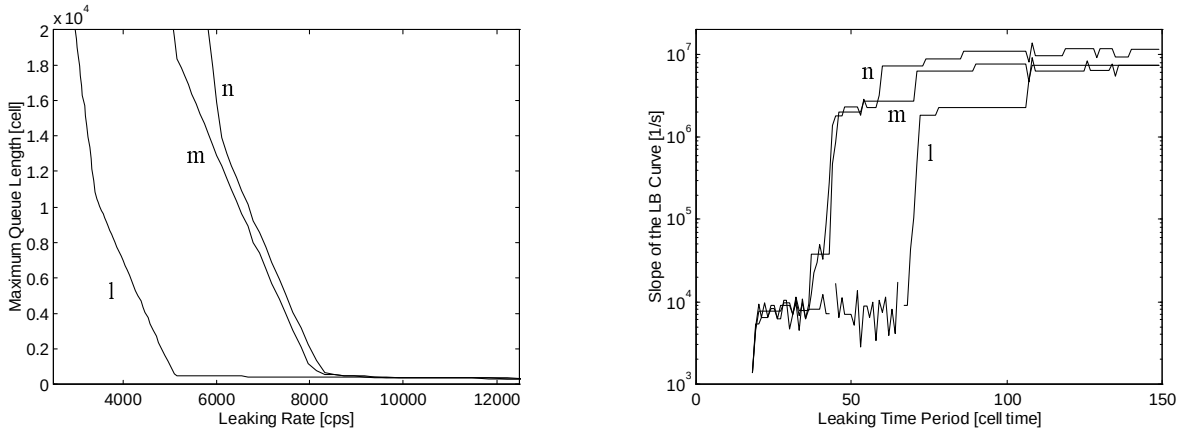

Figure 4 Effect Of Changes In Quality Setting: (l) 10 fps, (m) 20 fps, (n) 25 fps

One group of media parameters has no impact on the network resources (e.g. brightness) while the other parameter group changes the amount of data to be transferred [12]. The frame rate parameter belongs to the second group, as it can be seen in Figure 4. Although the amount of data is linearly proportional to the frame rate, the (m) and (n) curves are much closer to each other than to curve (l). A possible explanation to this phenomenon is that there is a finite upper limit of the performance of multimedia workstation, and it can not really support real-time pictures (25 fps). The slopes verify that the burst structures of the three traces are identical. The slope of (n) curve supports the hypothesis regarding the saturation of workstation performance.

Trace	Trace Length [s]	Event Number [cells]	Mean Cell Rate [kcps]	Burstiness	Cell Interarrival Time Variance	Comments
a	294.4211	1627720	5.5	140.3063	6.1758e+005	shaped to 35 kbps
b	19.5368	253627	12.9	700.6972	5.5935e+005	backgr. 100 Mbps
c	20.3794	264258	12.9	693.0733	5.5456e+005	backgr. 120 Mbps
d	20.138	260080	12.9	680.9803	5.5421e+005	backgr. 140 Mbps
e	68.9191	1000000	14.5	133.3298	8.5201e+004	aggregate
f	51.002	100309	1.96	179.8622	6.2775e+006	10 fps
g	45.602	138453	3.03	258.6941	3.7905e+006	10 fps
h	36.864	151544	4.11	345.9633	2.7542e+006	10 fps
i	45.678	307471	6.72	483.3476	1.4408e+006	10 fps
j	38.2679	250142	6.54	486.7423	1.5326e+006	10 fps
k	49.667	293180	5.89	452.2486	1.7524e+006	10 fps
l	35.7279	87353	2.44	197.9074	4.4541e+006	10 fps
m	32.4104	117899	3.64	245.1639	2.4926e+006	20 fps
n	45.2927	186966	4.12	226.8030	1.7907e+006	25 fps

Table 1 Traditional Parameters Of CBR And VBR Traffic Sources

3.3 Internet Traffic

Internet traffic is in the spotlight of many recent telecommunications research activities. The traffic of fundamental TCP/IP based applications such as File Transfer Protocol, Ping and WWW were analysed. The results are depicted in Figure 5. The Ping UNIX command was used with four different sizes of message (100, 256, 512 and 1024 cells). The q_B value is proportional to the message size in case of these four sources (s-v). A large size image was downloaded several times with a WWW browser; to get WWW sources (o,p) with a mean cell rate of 1.93 kbps. The $r_A - q_A$ and $r_B - q_B$ points of curve (o) are very close to each other, which means that it has a very simple burst structure determined by only a few bursts. A

large size file was downloaded during the FTP session. The LB slope curves of these sources (q,r) indicates the very simple bust structure.

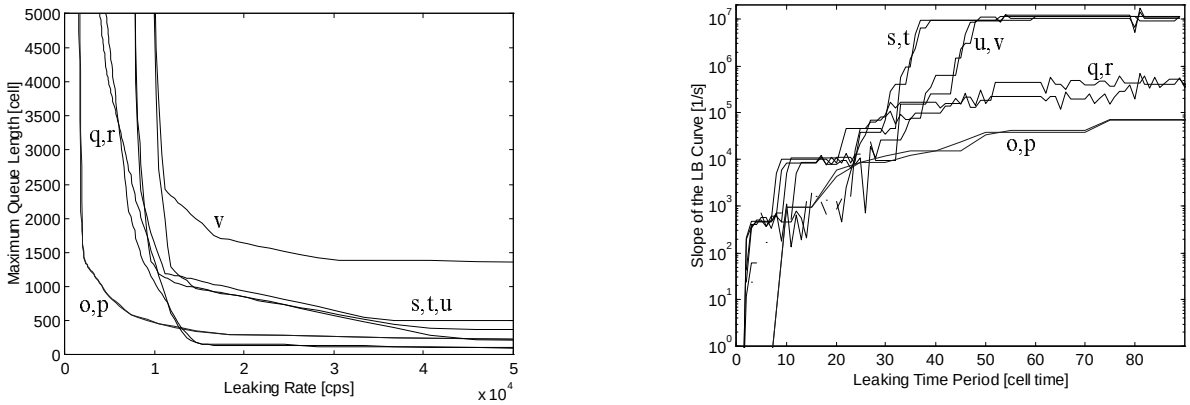

Figure 5 LB Curves Of Internet Traffic
(o,p) WWW Browsing, (q,r) FTP Sessions, (s-v) Ping Sessions

3.4 Aggregate Traffic

The LB curve of the aggregate traffic of four video sources, transferred through the Stockholm Gigabit Networks, was already presented in Figure 2. Internet traffic of interconnected LANs was also measured on the Swedish University Network (SUNET). Since these traces contain the largest number of captured cells (more than 83 million), these curves have the largest slope in case of large leaking time values and the largest q_A (Figure 6). Interesting is to recognise the similarity among the curves from independent measurements (w-z) both in the LB and the LB slope graphs.

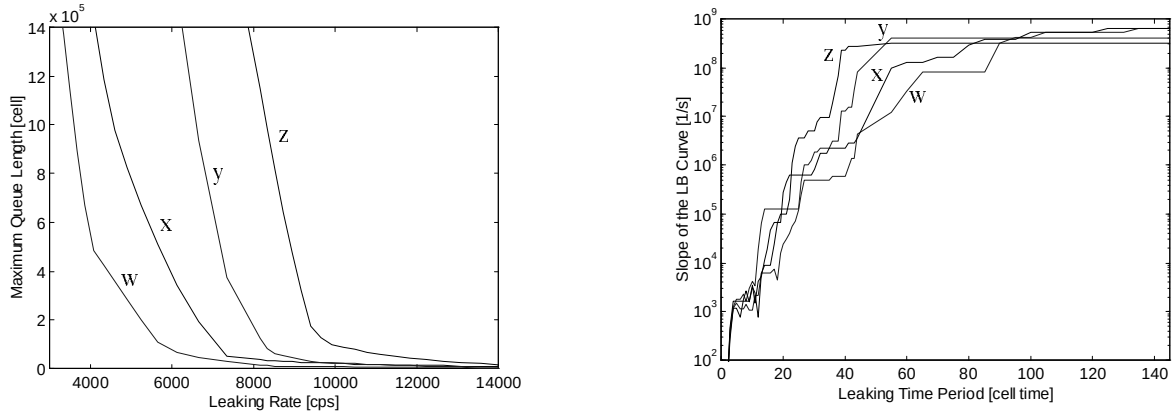

Figure 6 Aggregate Traffic Measured on SUNET

4 Robustness

An important feature of a practicable characterisation tool that it highlights the essential characteristics of the traffic and hides the unnecessary variations. Therefore an ideal tool gives exactly the same descriptors to each traces of a specific traffic, independently from the place and length of the trace. The impacts of these two factors on the result of the proposed Leaky Bucket Analysis method are presented in this section.

4.1 Repeatability

Many traces were captured from the same traffic type, using the same quality settings (e.g. video frame rate) in order to examine the repeatability of the method. The traffic types are different from the perspective

of determinism of cell generation. The VBR video traffic is easily reproducible, since the input video sequence can be repeated and most of the processes transforming and transferring the data inside of the multimedia workstation are of deterministic nature [8]. The only non-deterministic factor is the software application that gets the coded input video from the video card and sends the processed data unit to the protocol stack according to the scheduler of the operating system. That is why it can be assumed that traces taken from a VBR video traffic source have the same significant characteristics. This fact is noticeable in Figure 7 by showing the relative error ratio of LB curves calculated from different traces of the same source:

$$E(i) = \frac{2\left|q(t_i^1) - q(t_i^2)\right|}{\mathrm{E}\left\{q(t_i^1) + q(t_i^2)\right\}} \tag{6}$$

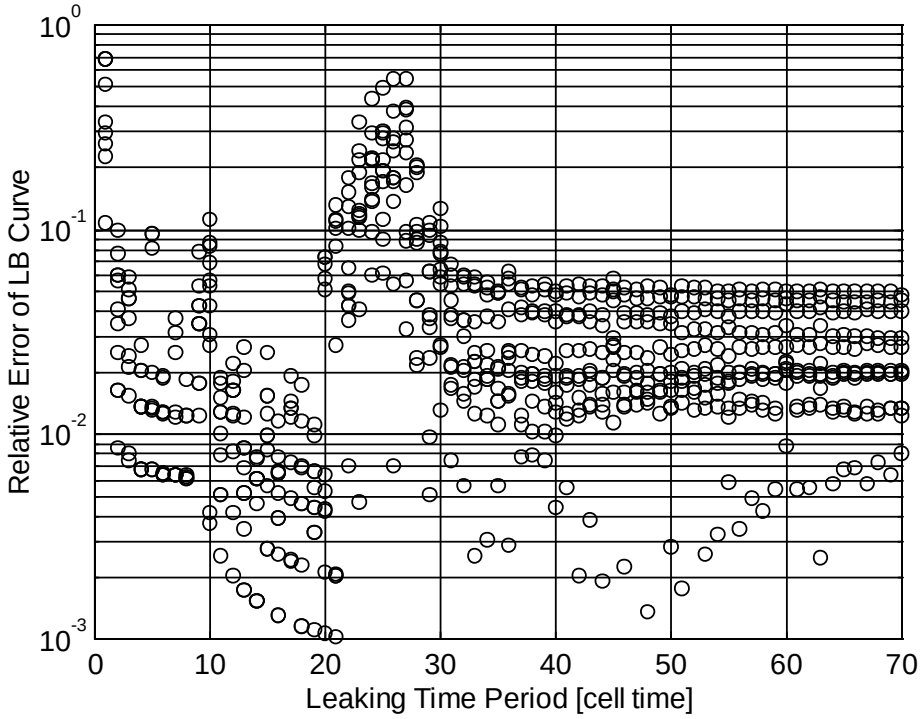

Figure 7 Repeatability Of VBR Video Traffic

The relative error has a peak between 20 and 30. This means about 40 ms i.e. the video frame rate set in the video application. As described above, the real frame rate is determined by the scheduling system and the upper limit of terminal's performance. This is a reasonable explanation for the degradation of repeatability on this track. Using this graph, a safety zone can be determined, where the points of LB curve should be evaluated with special care.

The same feature is not valid for other traffic types, like Internet traffic. In this case one can only assume that the sources have the same features in a statistical manner. To have a trustable statistical average, hundreds of traces should be taken from the same traffic. Here we examined only a couple of repetition in case of WWW, and FTP applications. The WWW session was repeated using a software tool called Service User Emulator [13], which can record and play back the interactions of user and this way it generates repeatable traffic. The LB curves initiated by the actions of the real user (o) and the emulated user (p) are presented in Figure 5. These curves are almost identical, while the two FTP traces (q,r) produced slightly different results.

4.2 Effect Of Trace Length

The traces of measured video traffic, captured before and after (b) multiplexing with CBR background traffic, were sliced into two and four parts in order to investigate the effect of event number on the shape of

the LB curve. The two original traces are depicted by continous lines, the two of half length with dashed and the quarter length trace by dotted lines in Figure 8.

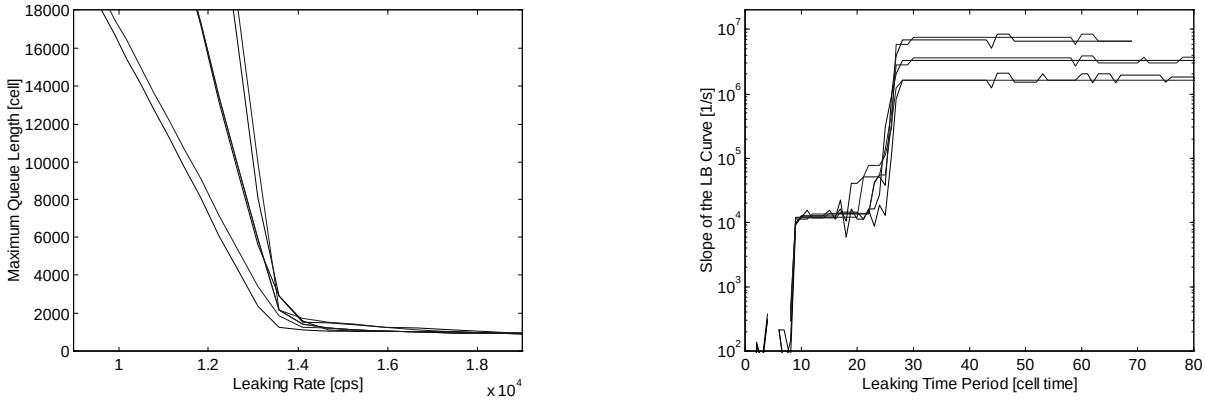

Figure 8 Effect Of The Number Of Cells In The Measured Trace

The results confirm the theoretical assumptions presented in Section 0. The value of s_A slope of each traces are proportional to the number of cells in the trace (Table 1). However the LB curves are almost identical for the $r_A<r$ (or $t_A>t$) part, supporting the proposed steps of our method.

5 Conclusion

In this paper, we introduced a simple and practical traffic characterisation tool called Leaky Bucket Analysis. The method has been described and demonstrated with examples taken from actual traffic measurements. The results show that besides the basic traffic characterisation parameters additional information can be gained about the burst structure and periodicity of ATM traffic. The robustness analysis provides a safety range of the curve. The practical applicability of the method for buffer dimensioning, shaper design, CAC design etc. are in the focus of our recent and future research activity.

6 Acknowledgements

The authors wish to thank Alexander Latour-Henner, Urban Hansson, Olof Pers, Aziz Miah, and Joakim Berkvist from Telia Research AB for their contributions to this paper and work during the measurements.

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