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ABSTRACT

This contribution (1) emphasizes the standardized CDV parameter in ITU-T Recommendation I.356, (2) summarizes work for CDV characteristics to date, (3) comments on the independence of delay between successive links in an end-to-end connection, and (4) presents some preliminary simulation results on the delay characterization in ATM networks.

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Some of the information contained in this contribution was used as an input to **AVC-635** *on ATM performance assumptions.*

Contact for the AVC Experts Group: Hayder M. Radha, AT&T Bell Laboratories
Contribution Author: Mahmood R. Noorchashm, AT&T Bell Laboratories

Cell Delay Variation (CDV) in ATM Networks

1. Introduction

Delay in ATM networks is a major subject of attention in companies planning to provide ATM transport as well as in academic, research, and standards organizations. The delay performance of the ATM network including its variations from cell to cell (Cell Delay Variation, CDV) should satisfy the requirements of the users at the application layer. CDV is a fundamental attribute of ATM transport. It is principally caused by the competing demands of cells to share the same resources, the same queue, or the same trunks.

In providing a CBR service, an essential function of the receiving AAL entity is to absorb the CDV in such a way that the resulting bit stream would satisfy the CBR jitter requirements. CBR services envisioned to be transported over the ATM networks such as voice and MPEG video are especially sensitive to CDV characteristics[1] [2]. Design of the receiving AAL entity for such applications requires insight into the nature of CDV for all ATM cells belonging to the target connection.

CDV between two measurement points (MPs) can be considered as a random variable and is dependent on the number of switches, multiplexers, cross connects, and the design of these intervening components. Cell Delay Variation is defined in I.356 Recommendation[3] in two related ways as follows.

1-point Cell Delay Variation

1-point CDV, y_k for cell k, at an MP is defined as the difference between the cell's reference arrival time (c_k) and actual arrival time (a_k) at the MP. The reference arrival time pattern (c_k) is defined as follows:

$$c_0=a_0=0, \qquad (1)$$

$$c_{k+1}=\begin{cases} c_k+T & \text{when} \quad c_k \ge a_k \\ a_k+T & \text{otherwise,} \end{cases}$$

where T is the peak emission interval.

2-point Cell Delay Variation

The 2-point CDV (v_k) for cell k between MP_1 and MP_2 is defined as the difference between the absolute cell transfer delay (x_k) of cell k between the two MPs and a defined reference cell transfer delay ($d_{1,2}$) between the same two MPs.

$$v_k=x_k-d_{1,2} \qquad (2)$$

The shape and span of the distribution of v_k is the same as the distribution of x_k. The specification of 2-point CDV objectives will be in terms of upper and lower quantiles. The specified upper and lower quantile values may depend on the negotiated peak cell rate.

2. *Previous Work to Characterize CDV*

Through a systematic approach AT&T has tried to characterize delay and CDV in ATM networks. Other companies have also produced simulation results with different sets of assumptions on the number of switches, traffic mix and trunk utilization. In the following paragraphs we summarize the results of other contributors. We then present AT&T's simulation work.

Shah[1] concludes through the simulation work carried out at Northern Telecom Inc that:

- For network supporting purely homogeneous CBR services no CDV build-up will be observed.
- For pure CBR with heterogeneous connections some CDV build-up will be observed.
- For CBR connections in which CDV already exist before entering the network CDV build up will be observed.
- The magnitude and distribution of cell delay variation depends on the type of connections sharing the link, the amount of CDV already present, and the trunk utilization.

In NT's simulation work eight nodes are assumed for the end-to-end connection. Two different utilizations (100% and 80%) have been considered. All sources except the target connection are dropped at each stage and fresh traffic added at the next stage in one configuration. In another trial 50% of the traffic is dropped at each stage with the other 50% at the next stage composed of fresh traffic. The sources were considered to be independent and their traffic was generated using the following models:

- Deterministic arrivals (no CDV)
- Uniform Interarrival time (i.e., The inter arrival time uniformly distributed over $[T-x, T+x]$, where T is the reciprocal of the peak cell rate of the connection.

Shah has used the inter arrival time between the cells at the receiving end as a measure of CDV. This is neither 1-point CDV nor 2-point CDV as defined in I.356. However it can be related to those parameters.

Jarrett[2], in an ongoing simulation work at Fujitsu Network Switching, concludes that: It is possible to estimate the CDV for an ATM network based on the Bellcore specifications[4]. He assumes an exponential distribution for the "waiting time" fit to these requirements. Delay in different links in the connection are assumed independent. This will allow the conclusion that the end-to-end delay distribution can be calculated through convolution of the component delay distributions. With this assumption the end-to-end delay distribution will be Erlang. Based on this approximation Jarrett estimated that CDV for a network of nine switches is less than 400 microseconds. He takes the difference between the $10^{-10}th$ quantile point of the delay distribution and the average delay as the definition for CDV.

In the next section we present the AT&T's ongoing simulation effort. CDV here is calculated as the difference between an upper and a lower quantile point.

3. *Simulation Model*

The ATM network is assumed to consist of connected ATM links, switches, and cross connects. ATM switches are assumed to have buffers at the output for each outgoing trunk. We assume that the connection under consideration can be modeled as the concatenation of several links in an end-to-end configuration as shown in Figure 1.

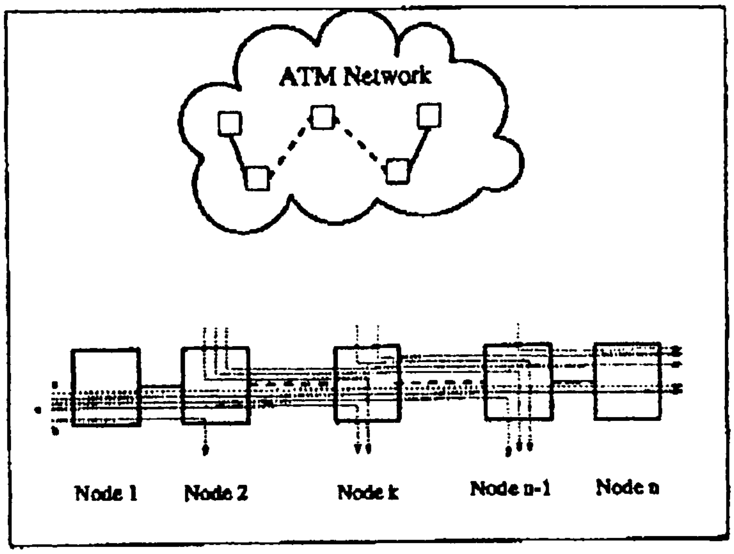

Figure 1. Model used in delay characterization

Various mixes of traffic can enter and leave at each intermediate node. The end-to-end delay consists of propagation delay, switching and queuing delay and delay corresponding to the CRC check and ATM layer operations. An end-to-end connection is assumed to traverse between 1-20 switches. The queues for the outgoing trunks use the FCFS discipline. For simplicity it is assumed that the only queuing processes are for the output trunks.

3.1 Question of Independence

Assuming n links in an end-to-end connection we calculate the delay by adding contributions from each link as follows:

$$x_{total}=x_1+x_2+\ldots x_n=\sum_{i=1}^{i=n}x_i \qquad (3)$$

If we assume that x_i are independent we can write the variance of the end-to-end delay as:

$$\sigma^2_{total}=\sum_{i=1}^{i=n}\sigma_i^2 \qquad (4)$$

If we further assume that all the links are identically distributed equation 4 will reduce to

$$\sigma^2_{total}=n\times\sigma_i^2 \qquad (5)$$

Taking the square root of both sides of this equation we get:

$$\sigma_{total}=\sqrt{n}\times\sigma_i \qquad (6)$$

If CDV is represented as a multiple of the standard deviation of delay, equation 6 can be used to find end-to-end CDV. This will be presented in a later contribution. The above argument is based on the independence assumption between various links in the connection. We attempted to verify this assumption by calculation of the correlation coefficient between delay in successive links of a simulation. Figure 2 presents this correlation coefficient as a function of the utilization relative to the traffic from other sources entering at intervening switches. The target connection is assumed to be submerged in a mix of traffic which is Poisson distributed and is replaced by fresh traffic at the downstream node.

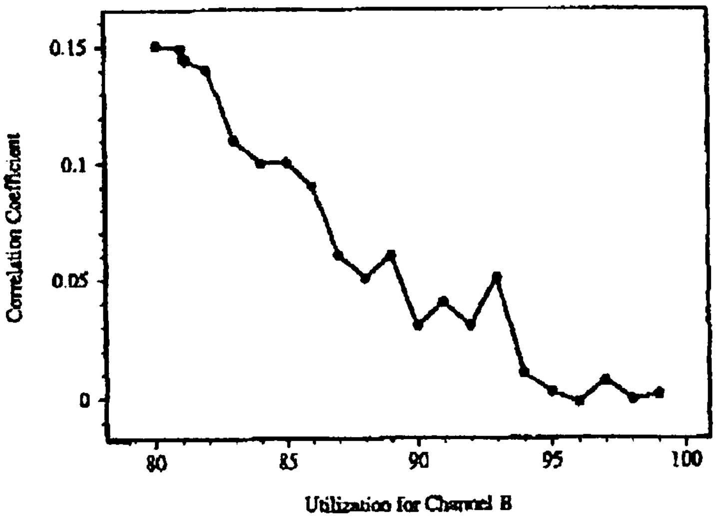

Figure 2. Coefficient of Correlation between two successive network links

In this figure Channel B represents the total traffic from other sources. It is noticed that the correlation coefficient approaches zero as the B-channel utilization gets large. Although diminishing of the correlation coefficient is the necessary condition for independence it is not sufficient. Moreover it is noted that as the target channel comprises a larger fraction of the total trunk capacity (i.e., as the ambient traffic diminishes,) correlation coefficient increases. This leads to the conclusion that the link delays in an end-to-end connection are not independent from one another in general.

4. Delay Simulation Taking the Dependence of Links Into Account

Considering that there may be dependence of delay in successive network links, we developed a program which simulates an ATM connection in as general a configuration as desired. The delay distribution can be calculated for the target connection with various number of switches and different mixes of traffic at the intermediate nodes. We assumed a CBR connection submerged in the traffic from other nodes/sources. Delay values are normalized to average service time. The model approximates an M/D/1 when the target channel constitutes a small fraction of the total trunk capacity. Figure 3 shows the simulation results for a connection consisting of between 2-20 switches.

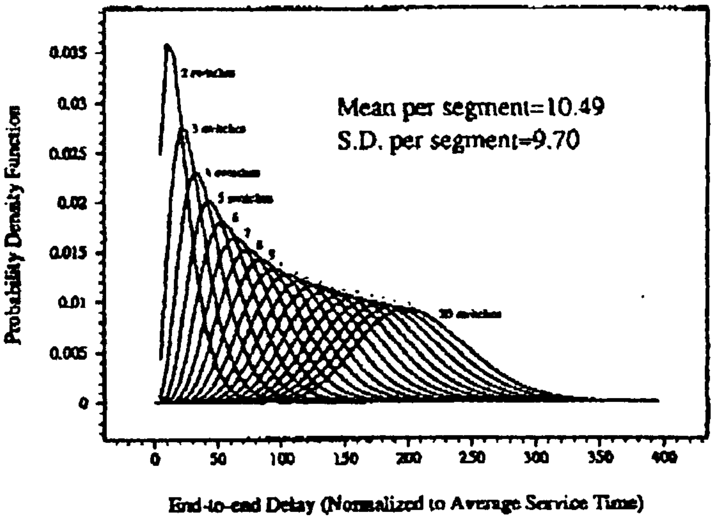

Figure 3. End-to-end delay distribution, 95% trunk utilization, .05% of which is occupied by target channel and 99% of which is occupied by B channel

The traffic from other nodes/sources enters at each node and leaves at the downstream node while it is replaced by fresh traffic of the same kind. The same trunk size (STS-3c) is used between all switches. The delay data is normalized to the average service time. If the difference between an upper and lower quantile points of the delay distribution is taken as Cell Delay Variation, a value of 350 service times can be calculated for 20 switches from the data represented in figure 3. If the number of switches are less in an end-to-end connection (which is quite reasonable) the accumulated CDV will be proportionally smaller. Note that since target channel occupies only 0.05% of the total trunk utilization, we expect that this simulation run should represent approximately independent links according to figure 2. To further verify this intuition we calculated the standard deviation of the cumulative delay for this simulation as a function of the number of links for the end-to-end connection. Figure 4 shows the result of this calculation.

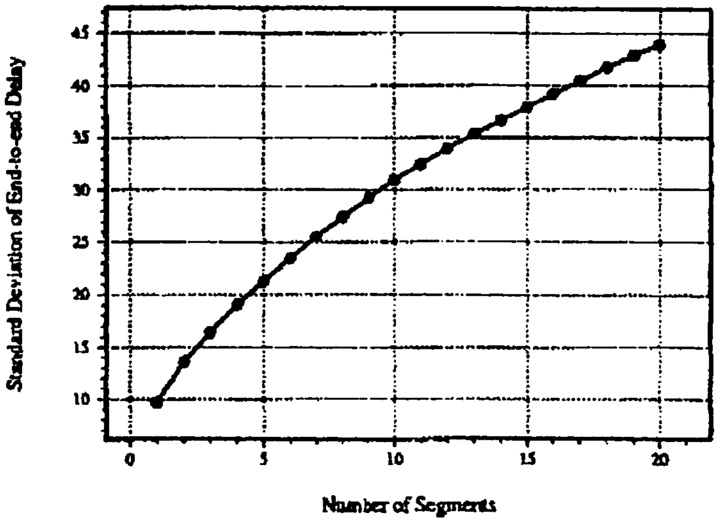

Figure 4. Delay standard deviation as a function of number of links in an end-to-end connection

It is clear from this figure that standard deviation varies as the square root of the number of links in the end-to-end connection. This confirms the result of equation 6.

5. *Conclusions*

Specification of CDV in terms of the difference between an upper and a lower quantile point of the delay distribution normalized to the average service time seems reasonable. A value of CDV equal to 350 service times as the $10^{-10}th$ quantile point of the delay distribution is anticipated for a maximum of 20 switches muxes and cross-connects. This gives a CDV of 0.96 milliseconds for a homogeneous connection consisting of exclusively STS-3c trunks. This is for peak hour operation with utilization of 95% and assumes, for simplicity, that queuing at the outgoing trunks dominate the end-to-end delay variations. It is possible that a mix of different service times corresponding to various trunk bit rates would give different results. We are examining more general traffic models (e.g., Batched Markov Arrival Process, BMAP). Generation of further results using these models is underway.

REFERENCES

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4. Bellcore TA-NWT-001110, Broadband ISDN Switching System Generic Requirements, Issue 2, August 1993.