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TITLE: Source/Network Model

PURPOSE: Proposal

Abstract

Enhancements to the simple source/network model described in AVC-22R are proposed. The effects of these modifications on the Statistical Multiplexing Gain are illustrated.

1. Introduction

The Experts Group have proposed a simple approximation to the average cell loss ratio which can be used in the calculation of statistical multiplexing gain for variable bit-rate coding. This approximation is based on specific assumptions about the video source rate distribution and the network characteristics. In this document the assumptions behind the simple source/network model are explored and some enhancements proposed. It is also suggested that, for further exploration of the impact of the network on the coding scheme, it will be necessary to obtain not only the average cell loss, but also the cell loss burst behaviour.

2. Network Model

For the purposes of discussion it is useful to separate the source and network models.

If the cell size is very small, then the cell arrival can be interpreted as a continuous flow. Under the assumption of a memoryless multiplexer, the cell loss rate can be approximated as a simple function of the total rate of the multiplex of sources. Under ideal conditions this loss function, *L(R)*, would be zero for rates below the capacity and then increase linearly above the capacity with a slope of one, i.e.

$$L(R) = \begin{cases} 0, & R \le C \\ R - C, & R > C \end{cases} \qquad (1)$$

where R is the total rate of the multiplexed sources and C is the network capacity.

There is a possibility that other loss functions may model the behaviour of the network more accurately. These are for further study.

The likely buffer sizes in ATM switches are of the order of 100 cells. Given that this buffering is shared by a large number of sources, its impact on the average cell loss behaviour will be relatively minor. Significantly larger buffer sizes will have an impact on the cell loss behaviour. Ignoring buffering in the network gives a higher average cell loss ratio, i.e. the results for statistical multiplexing gain will be conservative.

3. Source Model

The individual source bit rates are assumed to be independent and identically distributed random variables. In the first Experts Group model [AVC-22R] the individual source rates are assumed to be scaled Bernoulli random variables. That is, sources are either on, and transmitting at their peak rate, P, or off and not transmitting. The probability of a source being on is given by p, and hence a source's mean rate is $p.P$. The cell loss behaviour is a function of the rate distribution of the sum of the sources. When the individual sources are scaled Bernoulli random variables then the sum has a scaled binomial distribution.

For a sufficiently large number of sources it isn't necessary to model the individual source distributions. It is sufficient to know the mean and variance, which can be measured from the bit rate output of the source coder itself. Use of the mean and variance, rather than the specific assumption of an on/off source, along with the assumption that the total rate distribution is Gaussian, will provide a more realistic model for a large number of multiplexed sources.

For a small number of sources, accurate models of the source distributions are required and the on/off model is inappropriate. In [AVC-61] it was shown that the Gamma distribution accurately models the main component of an individual source's rate distribution, though the accuracy of the model in the tail (large source rates) is questionable.

4. Average Cell loss Ratio

Using the above models for the total source rate density function, and the loss function of the network, the average cell loss ratio[1] can be calculated as the average cell loss rate divided by the average cell transmission rate. That is

$$CLR = \frac{\int_0^{\infty} L(R) \cdot p(R) dR}{\mu_T} \qquad (2)$$

where, $L(R)$ is the loss rate function, $p(R)$ is the probability density function of the rate of the multiplexed sources and μ_T is the average rate of the multiplexed sources. The average rate of the multiplexed sources is the sum of the average rate of the individual sources. This expression gives the true cell loss rate, as distinct from the probability of saturation, which the original Experts Group model approximated. The original approximation proposed by the Experts Group is certainly easily calculated, however accuracy is preferable in studies of statistical multiplexing gain.

An expression for cell loss ratio, which applies when the sources are modelled by scaled Bernoulli distributions and the network is memoryless with a loss rate function given by (1), is contained in Appendix C of [AVC-38]. If a Gaussian model for the multiplexed rate distribution, and the ideal network model given in section 2, are assumed then the expression for cell loss can be written as

$$CLR = \frac{\frac{1}{\sigma_T \sqrt{2\pi}} \int_C^{\infty} (R - C) \cdot e^{-\frac{(R-\mu_T)^2}{2\sigma_T^2}} dR}{\mu_T} \qquad (3)$$

where, C is the capacity of the channel and σ_T^2 is the variance of the multiplexed sources, which is the sum of the individual source variances.

The table below evaluates the effect which use of the correct expression for cell loss ratio has on the number of multiplexed channels and the statistical multiplexing gains calculated. The data was obtained from a variable rate version of H.261 and coincides with that used in the experiments reported in [AVC-38], Table AVC-38/A2. Statistical multiplexing gains are obtained under the assumption of equal subjective qualities[2]. The method used for establishing equal subjective quality is described in [AVC-38]. The VBR coder has a mean rate of 139 Kbit/s and a peak rate of 556 Kbit/s. The CBR coder with equal subjective quality has a bit-rate of 256 Kbit/s. Note that these particular figures, and the choice of a comparison based on subjective quality, does not affect the overall conclusion. What is important is how the SMG estimates change with different model assumptions.

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[1]The terms cell loss rate and cell loss ratio have been used in contributions on this subject. The term cell loss ratio is more accurate and should be used.

[2]Note that this is slightly different from the usual definition of statistical multiplexing gain which is given by the ratio of the sum of the capacity that each source requires for a given loss, to the capacity required should the sources be multiplexed together and achieve the same loss.

CLR or P_{sat} (log10)	On/Off source, P_{sat} calculation *No. (SMG)*	On/Off source, *CLR* calculation *No. (SMG)*	Normal model, P_{sat} calculation *No. (SMG)*	Normal model, *CLR* calculation *No. (SMG)*
-3	818 (1.50)	914 (1.67)	903 (1.65)	954 (1.74)
-4	792 (1.45)	872 (1.59)	883 (1.61)	925 (1.69)
-6	749 (1.37)	814 (1.49)	852 (1.56)	884 (1.62)
-9	700 (1.28)	750 (1.37)	816 (1.49)	841 (1.54)

Table AVC-75/1. Number of channels and statistical multiplexing gain are shown for a number of different source/network models and different cell loss conditions. The network is assumed to have a capacity of 140 Mbit/s.

As the table indicates, the *SMG* calculated using the cell loss ratio is always greater than that obtained using P_{sat}. Since a large number of sources are being multiplexed, the results calculated under the assumption that the total rate distribution is Gaussian provide a more accurate estimate of the *SMG*. These results also indicate that the on/off source model gives a conservative estimate of *SMG*.

5. Cell Loss Rate Correlation

To obtain a realistic idea of the impact of the network on the performance of a video coder it is necessary to consider, not only the average cell loss rates, but also the temporal correlation of the cell loss rate.

In [1] it is shown that cell losses will occur in bursts. The results show a strong relationship between the burst behaviour of the sources and the average cell loss burst length. The simple memoryless network model, which has been used in this document, also suggests that cell loss will occur in bursts, if the individual input source rates are correlated over time. The average cell loss burst length will depend on the temporal correlation of the individual sources. For video, the source rates are highly correlated over several frames. This suggests that the cell loss bursts which will occur could extend over several frames. Clearly this will have a significant impact on the performance of video coding schemes, and must be considered in any codec design for an ATM network. Further work on this aspect is required.

6. Conclusions

A general method for calculating the average cell loss ratio given a set of independent, identically distributed sources, when the network is memoryless, has been proposed. This method is more accurate than the initial model proposed by the Experts Group. Shortcomings of the original model were recognised at the second meeting of the Experts Group in Paris (May 1991), but there was insufficient time available for discussion to resolve the issue. Australia proposes that the method for cell loss calculation, given in equation (2), be used for future network related studies.

The on/off distributional model of source rates gives conservative results for *SMG*. The Normal distribution can be used to model the multiplexed rate when the number of sources is large. More accurate source models, which can be used when the number of multiplexed sources is small, are for further study, though the Gamma distribution described in [AVC-61] is a potential candidate.

It has been emphasised that an understanding of the impact of the network characteristics on the coder will require a model of the cell loss burst behaviour.

References

[1] CCITT SG XVIII contribution, D.1047, Performance Evaluation Results on Cell Loss in ATM Network, NTT, Japan, Nov. 1990.