A Survey of Traffic Characterization Techniques in Telecommunication Networks

A. Rueda* and W. Kinsner

*Telecommunications Research Laboratories
10-75 Scurfield Boulevard
Winnipeg MB, R3Y 1P6, CANADA
arueda@win.trlabs.ca

Dept. of Electrical and Computer Engineering
University of Manitoba
Winnipeg MB, R3T 5V6, CANADA
kinsner@ee.umanitoba.ca

July 30, 1996

Abstract [1]

This paper presents a survey of existing techniques for traffic characterization in telecommunication networks with the objective of providing a framework for further research. Traffic characterization is an important aspect that has to be considered for efficient network management and control. This is specially important for the emerging B-ISDN, because the variety of sources and the nature of the multimedia information that these networks carry complicate the resource allocation problem. This paper provides a brief discussion and a list of traffic characterization references.

Keywords: Traffic characterization; broadband networks; ATM.

I. Introduction

The traffic characterization techniques for broadband networks found in the literature can be classified by the nature of the traffic descriptors into the following categories: autoregressive moving average (ARMA) models, Bernoulli process models, Markov chain models, neural network models, self-similar models, spectral characterization, transform-expand-sample (TES) models, traffic flow models, and wavelet models.

The following section provides an overview of the techniques and their applications. For more details see the list of references provided.

[1] Proceedings of the *1996 IEEE Canadian Conference on Electrical and Computer Engineering*, Calgary, Canada, vol. II, pp. 830-833, May 1996.

II. Review of the Techniques

The traditional traffic descriptors are those used in the statistical multiplexing process implemented in the asynchronous transfer mode (ATM) which is the standard for B-ISDN. Among them, the mean, peak and sustained rates, burst length, and cell-loss ratio have been extensively used (Paxson and Floyd [57]). These values capture only first-order statistics, and a need has been identified for descriptors that provide more information in order to describe highly correlated and bursty multimedia traffic (Veitch [59]).

The natural approach is the use of traditional traffic flow models which are useful in modeling of nodes (Caceres *et al.* [51], Chen and Mandelbaum [52]). Other concepts like packet-trains (Jain [53]) have also been proposed.

Different kinds of stochastic models reported in the literature have successfully been used in modeling traffic. For example, Markov chains are a useful tool in modeling communication systems (Heffes and Lucatoni [10]). It is widely accepted that the short-term arrival processes in telecommunication networks can be accurately described by Poisson processes, for example an FTP control connection which can be modeled as a Markov modulated Poisson process (MMPP) (Paxson and Floyd [57]).

However, it has been identified that the long-range dependencies found in multimedia traffic can be better described using the concept of self-similarity (Beran *et al.* [22], Addie and Zukerman [20], Leland *et al.* [34]) and autoregressive integrated moving average (ARIMA) models (Box and

Jenkins [1], Grunenfelder *et al.* [3], and Yegenoglu [4]), for example the FTP data communication arrivals (Paxson and Floyd [57]).

The concept of self-similarity (more accurately self-affinity) also known as fractality, was introduced by Mandelbrot [36] for the analysis of communication systems, as well as the concept of fractional Brownian noise [37]. Since then, these concepts have played a key role in compression techniques in signal processing and more recently in the analysis of network traffic ([20]-[40]). These models can capture long-term dependencies in traffic, which allows the use of higher order statistical measures as descriptors. A summary of fractal techniques has been presented by Kinsner [32].

Self-similarity refers to the property of an object to maintain certain characteristics when observed at different scales. The concepts of long-term dependency and self-similarity have been extensively studied by Taqqu [39]. Addie et al. [20] proposed the use of the term fractality in the sense that the autocovariance of the traffic exhibits self-similarity. Other self-similar models include fractional ARIMA processes (Grange and Joyeux [27]).

Self-similar models have been applied in variable-bit-rate (VBR) video (Beran et at. [22], Garrett and Willinger [26], Huang *et al.* [29], and McLaren and Nguyen [38]), LAN traffic Chen *et al.* [24], Dueck [25], and Leland *et al.* [34] [35]), traffic generation (Garrett and Willinger [26], Huang *et al.* [28], Lau *et al.* [33]), progressive image coding for packet-switching communications (Carlini *et al.* [23]), and estimation from noisy data (Kaplan and Kuo [30]).

Another approach suitable for modeling VBR video is based on TES models (Lee [46], Melamed *et al.* [47]-[49], Lambadaris *et al.* [45]). This approach takes advantage of the fact that successive video frames change very little and only scene changes or other abrupt changes can cause rate change in the video. Theoretical descriptions of the technique can be found in Fang *et al.* [42] and Lambadaris [45], and references therein. An application of TES to modeling MPEG video has been provided by Ismail *et al.* [44], and a software modeling tool has been introduced by Geist and Melamed [43]. TES models can also be used to generate traffic (Frost and Melamed [56]).

Neural networks have also been applied in traffic modeling in telecommunications for their ability to classify (Lippmann [15]) and implement nonlinear mappings. A review of training algorithms have been presented by Hiramatsu [14] and applications in communications have been discussed by Posner [18]. Neural networks are specially suitable for prediction (Neves [17]) and control (Necker [16] and Tarraf [19]).

Frequency domain techniques like spectral analysis has also been applied to model wide-band input processes in ATM networks (Alqaed and Chang [41]). In addition, wavelet coding has also been explored. Wavelets provide a convenient way to describe signals in the time-frequency domain (Schiff [55]). These have been applied with techniques like weighted finite automata, vector quantization, self-organizing maps, and simulated annealing (Frost and Melamed [56]).

Other surveys in the area have been presented by Frost and Melamed [56], Paxson and Floyd [57], Sen *et al.* [58], and Veitch [59].

III. Conclusions

As a result of this survey, we observed that the modeling techniques for multimedia traffic that are currently attracting the attention of the community are self-similarity and TES modeling. This is due to the need to describe the complex nature of the non-uniform traffic. In addition, neural network techniques can be very useful for prediction and control.

The authors hope that this survey will provide the reader with useful information on the current techniques for traffic modeling in broadband networks.

IV. Acknowledgment

The authors gratefully acknowledge the information provided by Jeff Diamond for this survey.

References

ARMA Models

[1] G. Box and G. Jenkins, *Time Series Analysis: Forecasting and Control.* Englewood Cliffs, NJ: Prentice-Hall, 1976.

[2] M. Nomura, T. Fujii, and N. Ohta, “Basic characteristics of variable rate video coding in ATM environment”, *IEEE J. on Selec. Areas Commun.*, vol. 7, no. 5, June 1989.

[3] R. Grunenfelder, J. Cosmas, S. Manthorpe, A. Odinma-Okafor, “Characterization of video codecs as autoregres-

sive moving average processes and related queuing systems performance", *IEEE J. Selected Areas on Communications*, vol. 9, no. 3, pp. 284-293, 1991.

[4] F. Yegenoglu, B. Jabbari, and Y. Zhang, "Motion-classified autoregressive modeling of variable bit Rate Video", *IEEE Trans. on Circ. Syst. Video Tech.*, vol. 3(1), February 1993.

Bernoulli Models

[5] M. Lee and D. Ahn, "Cell loss analysis and design trade-offs of nonblocking ATM switches with nonuniform traffic", *IEEE/ACM Trans. on Networking*, vol. 3, no. 2, pp. 199-210, April 1995.

Markov Chain Models

[6] R. Addie and M. Zukerman, "A gaussian traffic model for a B-ISDN statistical multiplexer", in *Proc. IEEE Globecom*, Dec. 1992.

[7] R. Addie and M. Frater, "Loss forecasting by means of gaussian models of video traffic", in *Proc. 8th ATRS*, Melbourne, Australia, Dec. 1993.

[8] R. Addie and M. Zukerman, "A gaussian characterization of correlated ATM multiplexed traffic and related queueing studies", in *Proc. IEEE Int. Conf. Commun.*, June 1993.

[9] K. Fendick and W. Whitt, "Measurements and approximations to describe the offered traffic and predict the average workload in a single-server queue", in *Proc. IEEE*, vol. 77, pp. 171-194, 1989.

[10] H. Heffes and D. Lucantoni, "A Markov modulated characterization of packetized voice and data traffic and related statistical multiplexer Performance", *IEEE J. Select. Areas Commun.*, vol. SAC-4, pp. 856-868, 1986.

[11] D. Heyman, A. Tabatabai, and T. Lakshman, "Statistical analysis and simulation study of video teleconference traffic in ATM networks", in *Proc. Globecom*, pp. 21-27, 1991.

[12] S. Li, S. Chong, and C. Hwang, "Link capacity allocation and network control by filtered input rate in high-speed networks", *IEEE/ACM Trans. on Networking*, vol. 3, no. 1, pp. 10-25, February 1995.

[13] M. Livny, B. Melamed, and A. Tsiolis, "The impact of autocorrelation on queuing systems", *Management Science*, vol. 39(3), pp. 322-339, 1993.

Neural Network Models

[14] A. Hiramatsu, "Training techniques for neural network applications in ATM", *IEEE Commun. Mag.*, pp. 58-67, October 1995.

[15] R. Lippmann, "Pattern classification using neural networks", *IEEE Commun. Mag.*, pp. 47-64, November 1989.

[16] T. Necker, T. Renger and H. Kroner, "Bitrate management in ATM systems using recurrrent neural networks", in *Proc. IEEE Globecom*, pp. 1774-1779, 1994.

[17] J. Neves, M. Leitao, and L. Almeida, "Neural networks in B-ISDN flow control: ATM traffic prediction or network modeling?", *IEEE Commun. Mag.*, pp. 50-56, October 1995.

[18] E. Posner, "Neural networks in communications", *IEEE Trans. on Neural Networks*, vol. 1, no. 1, pp. 145-147, March 1990.

[19] A. Tarraf, I. Habib, and T. Saadawi, "Intelligent traffic control for ATM broadband networks", *IEEE Commun. Mag.*, pp. 76-82, October 1995.

Self-similar Traffic Models

[20] R. Addie, M. Zukerman, and T. Neame, "Fractal traffic: measurements, modelling and performance evaluation", in *Proc. IEEE Infocom*, pp. 977-984, 1995.

[21] R. Addie and M. Zukerman, and T. Neame, "Performance of a single server queue with self-similar Input", in *Proc. IEEE Int. Conf. Commun.*, June 1995.

[22] J. Beran, R. Sherman, M. Taqqu, and W. Willinger, "Long-range dependence in variable-bit-rate video traffic", *IEEE Trans. on Communications*, vol. 43, no. 4, pp. 1566-1579, April 1995.

[23] P. Carlini, S. Giordano, M. Pagano, and F. Russo, "Self-similar progressive image coding scheme for multimedia packet switching communications", in *Proc. IEEE Int. Conf. on Commun.*, pp. 1768-1772, Seattle 1995.

[24] Y. Chen, Z. Deng, and C. Williamson, "A model for self-similar ethernet LAN traffic: design, implemntation, and performance implications", *Internal Report, University of Saskatchewan*, Canada, 1995.

[25] D. Dueck, "The fractal nature of ethernet traffic", internal report, University of Manitoba, Dept. of Elect. and Comp. Eng. and Telecomm. Research Labs, Canada, April 1995.

[26] M. Garrett and W. Willinger, "Analysis, modeling and generation of self-similar VBR video traffic", in *Proc. ACM Sigcom*, London, UK, pp. 269-280, 1994.

[27] C. Grange and R. Joyeux, "An introduction to long-memory time series models and fractional differencing", *Time Series Analysis*, vol. 1, pp. 15-29, 1980.

[28] C. Huang, M. Devetsikiotis, I. Lambadaris, and A. Kaye, "Fast simulation of self-similar traffic in ATM networks", in *Proc. IEEE Int. Conf. on Commun.*, Seattle 1995.

[29] C. Huang, M. Devetsikiotis, I. Lambadaris, and A. Kaye, "Modeling and simulation of self-similar variable bit rate compressed video: a unified approach", in *Proc. ACM Sigcom*, Cambridge 1995.

[30] L. Kaplan and C. Kuo, "Fractal estimation from noisy data via discrete fractional gaussian noise (DFGN) and the Haar basis", *IEEE Trans. on Signal Proc.*, vol. 41(12), pp. 3554-3562, Dec. 1993.

[31] L. Kaplan and C. Kuo, "Extending self-similarity for fractional browninan motion", *IEEE Trans. on Signal Proc.*, vol. 42(12), pp. 3526-3530, Dec. 1994.

[32] W. Kinsner, *Fractal and Chaos Engineering*, Course Notes, Dept. of Electrical and Computer Eng., University of Manitoba, 1994.

[33] W. Lau, A. Erramilli, J. Wang, and W. Willinger, "Self-similar traffic generation: The random midpoint displacement algorithm and its properties", in *Proc. IEEE Int Conf. Commun.*, 1995.

[34] W. Leland, M. Taqqu, W. Willinger, and D. Wilson, "On the self-similar nature of ethernet traffic (extended version)", *IEEE/ACM Trans. on Networking*, vol. 2, no. 1, pp. 1-15, February 1994.

[35] W. Leland, M. Taqqu, W. Willinger, and D. Wilson, "Self-similarity in high-speed packet traffic: analysis and modeling of ethernet traffic measurements", *Statistical Sc.*, 1994.

[36] B. Mandelbrot, "Self-similar error clusters in communication systems and the concept of conditional stationarity", *IEEE Trans. on Communication Technology*, pp. 71-90, 1965.

[37] B. Mandelbrot and J. Van Ness, "Fractional Brownian motions, fractional noises and applications", *SIAM Review*, vol. 10, pp. 422-437, 1968.

[38] D. McLaren and D. Nguyen, "A fractal-based source model for ATM packet video", in *Proc. Int. Conf. on Digital Processing of Signals in Communications*, Univ. of Loughbovough, September 1991.

[39] M. Taqqu, "A bibliographical guide to self-similar processes and long-range dependence", in *Dependence in Probability and Statistic*, E. Eberlein and M. Taqqu (Eds.), Birkhaeuser, Basel, pp. 137-165, 1985.

[40] V. Paxson, "Fast approximation of self-similar network traffic", *Report* LBL-36750, Univ. of California at Berkeley, Lawrence Berkeley Laboratory, 1995.

Spectral Characterization

[41] A. Alqaed and C. Chang, "Traffic description using spectral characterization of wide-band input processes in ATM networks", in *Proc. IEEE Int. Conf. on Communications*, pp. 182-186, Seattle 1995.

TES Models

[42] Y, Fang, M. Devetsikiotis, I. Lambadaris, and A. Kaye, "Exponential bounds for the waiting time distribution in Markovian queues, with applications to TES/GI/1 systems", in *Proc. ACM Sigmetrics*, 1995.

[43] D. Geist and B. Melamed, "TEStool: an environment for visual interactive modeling of autocorrelated traffic", in *Proc. IEEE Int. Conf. Commun.*, pp. 1285-1289, 1992.

[44] M. Ismail, I. Lambadaris, M. Devetsikiotis, and A. Kaye, "Modeling prioritized MPEG video using TES and a frame spreading strategy for transmission in ATM networks", in *Proc. IEEE Infocom*, Boston 1995.

[45] I. Lambadaris, M. Devetsikiotis, A. Kaye, M. Ismail, C. Sharon, Y. Fang, and C. Huang, "Traffic modelling and design methodologies for broadband networks", *Canadian J. on Electrical and Computer Eng.*, vol. 20, no. 3, 1995.

[46] D. Lee, B. Melamed, A. Reibman, and B. Sengupta, "Analysis of a video multiplexer using TES as a modeling methodology", in *Proc. IEEE Globecom*, pp. 16-19, 1991.

[47] B. Melamed and B. Sengupta, "TES modeling of video traffic", *IEICE Trans. on Communications*, vol. E75-B, no. 12, pp. 1292-1300, Dec. 1992.

[48] B. Melamed and D. Pendarakis, "A TES-based model for compressed Star Wars video", In *Proc. Comm. Theory Mini-Conf, IEEE Globecom*, San Francisco 1994.

[49] B. Melamed, D. Raychaudhuri, B. Sengupta, and J. Zdepski, "TES-based video source modeling for performance evaluation of integrated networks", *IEEE Trans. Comm.*, vol. 42(10), Oct. 1994.

Traffic Flow Models

[50] M. Braun, C. Coleman, and D. Drew (Eds.), *Differential Equation Models.* New York: Springer-Verlag, 1983.

[51] R. Caceres, P. Danzig, S. Jamin, and D. Mitzel, "Characteristics of wide-area TCP/IP conversations", in *Proc. ACM Sigcomm*, 1991.

[52] H. Chen and A. Mandelbaum, "Discrete flow networks: bottleneck analysis and fluid approximation", *Mathematics of Operations Research*, vol. 16, no. 2, pp. 408-446, May 1984.

[53] R. Jain and S. Routhier, "Packet trains - measurements and a new model for computer network traffic", *IEEE J. Select. Areas Commun.*, vol. 4, pp. 986-995, 1986.

Wavelet Models

[54] P. Flandrin, "Wavelet analysis and synthesis of fractional brownian motion", *IEEE Trans. on Information Theory*, vol. 38(2), pp. 910-917, March 1992.

[55] S. Schiff, "Resolving time-series structure with a controlled wavelet transform", *Optical Engineering*, vol. 31(11), pp. 2492-2495, Nov. 1992.

Other Surveys

[56] V. Frost and B. Melamed, "Traffic modeling for telecommunication networks", *IEEE Commun. Mag.*, pp. 70-81, March 1994.

[57] V. Paxson and S. Floyd, "Wide area traffic: the failure of Poisson modeling", *IEEE/ACM Trans. on Networking*, vol. 3, no. 3, pp. 226-244, June 1995.

[58] P. Sen et al., "Models for packet switching of variable-bit-rate video sources", *IEEE J. on Select. Areas Commun.*, vol. 7, no. 5, pp. 865-869, 1989.

[59] D. Veitch, "Novel models of broadband traffic", in *Proc. IEEE Globecom*, pp. 1057-1061, 1993.