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A Bibliographical Guide to Self-Similar Traffic and Performance Modeling for Modern High-Speed Networks

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Abstract

This paper provides a bibliographical guide to researchers and traffic engineers who are interested in self-similar traffic modeling and analysis. It lists some of the most recent network traffic studies and includes surveys and research papers in the areas of data analysis, statistical inference, mathematical modeling, queueing and performance analysis. It also contains references to other areas of applications (e.g., hydrology, economics, geophysics, biology and biophysics) where similar developments have taken place and where numerous results have been obtained that can often be directly applied in the network traffic context. Heavy tailed distributions, their relation to self-similar modeling, and corresponding estimation techniques are also covered in this guide.

A fundamental feature of *self-similar* or *fractal* phenomena is that they encompass a wide range of time scales. In the teletraffic literature, the notion of *burstiness* is often used in this context. Mathematical models that attempt to capture and describe self-similar, fractal, or bursty phenomena in a parsimonious manner include certain self-similar stochastic processes and appropriately chosen dynamical systems. A common characteristic of these models is that their space-time dynamics is governed *parsimoniously* by *power-law* distribution functions (the "Noah Effect") and *hyperbolically* decaying autocorrelations(the "Joseph Effect"). In sharp contrast, traditional approaches to modeling fractal phenomena typically rely on *highly parameterized* multilevel hierarchies of conventional models which, in turn, are characterized by distribution and autocorrelation functions that decay *exponentially fast*.

Although bursty or fractal phenomena have been observed in virtually all branches of science and engineering, and fractal models have been applied with with some success in areas, such as hydrology, financial economics, and biophysics, they are new to teletraffic theory and represent a recent addition to the already large class of alternative models for describing traffic in packet switched networks. While most applications of fractal models in science and engineering have been based on empirical findings, they have almost exclusively focused on the models' powerful descriptive capabilities; their engineering implications and analyses have been largely ignored, mainly because fractal models are generally viewed to be very difficult to analyze. In contrast, the success of fractal models in teletraffic theory will only partly depend on how well they describe actual network traffic, but will also depend to a large degree on the ability to use these models in network analysis and control. To this end, this bibliographical guide brings together many of the references that (i) report on real-time traffic measurements from working networks and emphasize the importance of data analytic, statistical inference and mathematical modeling methods for modern traffic and performance modeling, (ii) demonstrate how traditional modeling approaches, applied with great success in conventional telephony (i.e., circuit switching), have dealt with the increasingly bursty behavior of traffic resulting from modern packet communications, and (iii) illustrate the emergence and impact of fractal processes in modern high-speed network traffic modeling and performance analysis. Thus, this guide lists some of the most recent network traffic studies, combines the most relevant survey and research papers in the areas of data analysis, statistical inference and mathematical modeling, and contains references to other areas of applications (i.e., hydrology, economics and biophysics) where similar developments have taken place. Special emphasis is given to recent works that take fractal models beyond their descriptive phase and pursue genuine engineering applications in the area of modern high-speed network design, management, and control; e.g., queueing models, performance analysis,, and control theory. While we do not claim that this is a comprehensive bibliography (for example, note that we did not attempt to adequately cover the traditional teletraffic literature, and including the very latest developments in this rapidly growing field is nearly impossible), we hope that it will serve as a useful, up-to-date reference for researchers and traffic engineers who are interested in self-similar traffic modeling and analysis.

Historically, traffic modeling has its origins in conventional telephony, and has been based almost exclusively on *Poisson* (or, more generally, *Markovian*) assumptions about traffic arrival patterns and on *exponential* assumptions about resource holding requirements (e.g., [144,209]). However, the emergence of modern high-speed packet networks combines drastically new and different transmission and switching technologies with dramatically heterogeneous mixtures of services and applications. As a result, packet traffic is generally expected to be more complex or bursty than voice traffic, simply because it is spanning vastly different time scales, from microseconds to seconds and minutes. Traditional traffic modeling has responded to these developments with a steady supply of novel and increasingly sophisticated stochastic models: fluid flow models [9], Markov-Modulated Poisson processes [180], different variations of packet train models [96, 210, 349, 350], the versatile Markovian arrival processes (MAPs) [316, 317], batched Markovian arrival process models (BMAPs) [277], TES (Transform-Expand- Sample) models [305]. While the development of these and other models has been mainly driven by the desire of maintaining analytic tractability of related queueing and performance problems, the resulting models are almost never judged by how well they fit actual traffic data in a statistical sense [12] (for a critical discussion, see [327, 348, 413]).

While the availability of actual traffic measurements from working packet networks has been a serious problem in the past (see [329, 330], where it is noted that between 1966 and 1987, several thousand papers on queueing problems have been published, but only about 50 on traffic measurement results), more recently, enormous volumes of traffic data from working networks have been collected and made available to researchers: CCSN/SS7 [106, 107], ISDN [122, 304], Ethernet LANs [173–175, 255–260, 293, 378, 409–412], WANs and NSFNet [41, 68, 69, 88, 181, 220, 314, 331–333, 335], and VBR traffic [26, 145, 146, 186, 199]. Other traffic measurement studies we are aware of include [346] (Ethernet traffic to a file server), [5] (FASTPAC, an Australian high-speed data network), [59] (DQDB MAN environment), and [78] (World-Wide-Web traffic). Some of these data consist of high-resolution traffic measurements over hours and days/weeks (e.g., [26, 41, 106, 146, 174, 186, 220, 255, 256, 260, 304, 331, 332, 346], others provide information on coarser time scales over time periods ranging from weeks to months/years (e.g., [69, 333]). The former are typically used for traffic characterization purposes, and the latter yield insight into long-term growth trends and network utilizations. Extensive recent statistical analyses of high time-resolution traffic measurements reported in [26, 107, 122, 146, 150, 199, 220, 256, 331, 410, 411] have provided convincing evidence that actual traffic data from working packet networks are consistent with statistical *self-similarity* or *fractal* characteristics. Moreover, these empirically observed features often distinguish clearly between traffic generated by traditional models and measured data [409, 410]. The main reason for this clear distinction is a subtle difference in the underlying dependence structure; while traditional packet traffic models are *short-range dependent* (i.e., have exponentially decaying autocorrelations), measured packet traffic data are consistent with *long-range dependence* (i.e., hyperbolically decaying autocorrelations).

The probability theory of self-similarity and long-range dependence is discussed in [22, 24, 77, 171, 177, 287, 389, 390, 402]. The books [130, 178, 337, 338] also contain large sections on self-similar processes, and extensive bibliographies can be found in [14, 22, 24, 287, 374, 389]. Self-similar stochastic processes were introduced by Kolmogorov [239] in a theoretical context and brought to the attention of probabilists and statisticians by Mandelbrot and his co-workers [287–292]. They have been used in hydrology [200–202, 214, 254, 302, 310–312], geophysics [40, 322], biophysics [143, 267–269], and biology [339, 340]. An area of application where self-similarity and long-range dependence continue to play a significant role and where many results of practical relevance for traffic engineering have been discovered is economics or, more precisely, financial economics [15, 17, 31, 50, 51, 54, 75, 83, 167, 168, 273, 284, 297, 342, 383]. The paper [14] provides an overview. For an early application of the self-similarity concept and related topics to communications systems, see the seminal paper by Mandelbrot [283]. Enlightening philosophical discussions centering around the issues of traditional mathematical modeling (based on Markov processes) versus unconventional fractal modeling (based on concepts, such as self-similarity or long-range dependence), as well as technical issues related to the problem of stationarity and long-range dependence versus non-stationarity can be found in [103,104,205,219,246,266,303]. Methods for dealing with non-stationarity are developed in [18, 343, 399].

From a modeling viewpoint, the two major families of self-similar time series models are *fractional Gaussian noises* (i.e., the increment processes of *fractional Brownian motion*) [24,288,289,374] and *fractional ARIMA processes* [166, 195, 196], a generalization of the popular ARIMA time series models [33, 37]. Techniques for identifying fractional ARIMA models (also called FARIMA or ARFIMA) are discussed in [23, 310]. Other stochastic approaches to modeling self-similar features are considered in [28, 156, 160, 274, 275, 369, 371] (based on shot-noise processes), [373] (linear models with long-range dependence), [30,261, 262, 276, 284, 411, 412] (renewal reward processes and their superposition), [116, 283,401] (renewal processes or "zero-rate" processes), [165] (aggregation of simple short-range dependent models), and [135, 294, 414, 416] (wavelet analysis). Further models are considered in [16,19,176,313,379,386,403,417]. A radically different approach to modeling self-similar phenomena relies on ideas from the theories of chaos and fractals [73, 97, 118–120, 124, 125, 171, 250, 287, 337, 344, 345, 377]; for a general discussion on chaos, probability and statistics, see [29, 46, 47]

An overview of statistical inference methods for self-similar models and random processes with long-range dependence can be found in [22, 24], the papers [392–394] listing additional techniques. More specifically, R/S analysis is discussed in [18, 24, 26, 28, 130, 200, 258, 272, 273, 286, 288, 290–292, 302, 310, 394] (see also [10,131]), variance-time analysis in [24,26,77,258,310,331,394,399] and for spectral domain methods using periodograms, see [24, 26, 48, 84, 140, 149, 157, 159, 183, 203, 204, 206, 249, 253, 353, 357–366, 393, 407, 418].

Examples of new statistical techniques in this area include [3, 7, 20, 21, 25, 27, 52, 53, 57, 58, 80–82, 86, 98, 99, 154, 155, 189, 190, 197, 247, 258, 381, 382, 410, 415]. For a practical evaluation of the different techniques see [392–394]. The paper [76] provides a general overview on the statistical analysis of time series, and references [123,301,355] comment on some of the shortcomings of traditional time series analysis in the presence of large sets of traffic measurements. The problem of estimating a linear or polynomial regression when the errors have long-range dependence is considered in [85, 154, 241, 370, 418, 419]. Prediction problems in the context of long-range dependence are addressed in [24, 169, 336, 352].

The theoretical background behind many of these statistical tools is based on central and non-central limit theorems for random sequences with long-range dependence [34,100,139,141,142,152,153,158,159,161,162,164,182,188,191–193, 280, 387, 388, 395–397]. The proofs require understanding the structure of moments of non-linear functions of Gaussian random variables and linear processes [34,94,158,182,280,385,398]. Some of the results have been extended to random fields, that is, to processes where the "time" parameter is viewed as a "space" parameter and is multidimensional [11, 148, 179, 185, 208, 278, 279, 341, 375].

Besides the statistical and practical aspects of self-similar or fractal models, there is the ever-present desire for a physical or phenomenological "explanation" for the fractal nature of empirically observed data. For recent work on this topic in the context of high-speed network traffic modeling and how it relates to the *infinite variance syndrome* or *heavy-tailed behavior* (the "Noah Effect") of individual mechanisms that are responsible for the self-similarity property at the aggregation level, see [107,220,248,258,326,331,409–412] and related earlier results reported in [77,261,284]. Explaining and validating (with actual data) self-similarity on physical grounds in a network context result in (i) less resistance to non-traditional modeling approaches [77, 103], (ii) new insight into the essential characteristics of modern high-speed network traffic, and (iii) novel approaches for dealing with problems related to network traffic management and control. In this context, statistical methods for dealing with heavy-tailed phenomena and appropriate modeling techniques are of crucial importance. Moreover, in terms of modeling, the insight gained into the relationship between the "Noah Effect" exhibited by the individual mechanisms and the "Joseph Effect" observed at the aggregation level provides convincing evidence in favor of applying *the principle of parsimony* or *Ockham's Razor* [117, 147, 212, 411–413]; see [32, 107] for a particular example involving call holding time modeling for ordinary telephony.

The relevance of heavy-tailed modeling for teletraffic data is also the subject of the recent survey paper [355]. Empirically, the heavy-tailed counterpart of the Gaussian distribution is the stable distribution [126, 128, 132, 420]. While a Gaussian distribution is always symmetric around the mean or median, a stable distribution can be either symmetric or skewed. It has three parameters, α, β, and μ; α characterizes the heaviness of the tail, β the skewness and μ the drift. The stable distribution is symmetric around μ when $\beta = 0$ and is maximally skewed to the right when $\beta = 1$. Numerical tables of stable distributions can be found in [38, 108, 194, 296, 300, 324, 325, 374]. The books [211, 374] provide a systematic treatment of stable time series and processes. There are infinite variance counterparts to fractional Gaussian noise [372–374], FARIMA [232,233, 235, 374] but also pulse-based models [60–62]. Infinite variance models are also of interest in economics and finance [126,127,281,282,297,307–309,347,371]. For random fields with infinite variance, see [225–227, 231].

The covariance, which is used to describe the dependence, is not defined when the variance is infinite. Alternatives include the covariation which enters in formulas for regression [43, 45, 63–67, 136, 137, 374] and the codifference which also characterizes the "ergodic" properties of the time series [13, 170, 211, 230, 231, 237, 321, 367, 368, 374].

Estimation of the exponent α characterizing the heaviness of the distribution is of central importance and is one of the main themes in [355]. One way of estimating α is to use regression in a log-log plot [87,91,112,187,244,298,354,380]. Other methods are considered by [39, 109–111, 129, 242, 243, 295, 299, 315, 355]. Note that even though the variance is infinite one can still use spectral methods to estimate the unknown parameters in a model [92,221–223,228,238]. In particular, the Whittle-type estimator is still applicable [224,234,236,238,306]. One can also use M-estimators [90], in particular estimators based on least absolute deviation [89], and also the bootstrap [93]. For prediction, see [42, 44, 70, 71, 229].

While from a statistical viewpoint, the distinction between traditional traffic models and measured network traffic is significant and intriguing, there is also mounting evidence that the empirically observed fractal features of actual traffic (in particular, long-range dependence and heavy-tailed distributions) has practical implications for a wide range of network design and engineering problems. Traditional Markovian (or more general, short-range dependent) input streams to queues are known to impact queueing performance (see for example, [6, 104, 113, 133, 134, 207, 240, 263, 264, 271, 351, 384, 400]), and a range of techniques (e.g., [101, 163, 251, 265, 317, 405]) are by now available to quantify these impacts and their implications for network management and control. For example, considerable attention has been paid in the recent past to the problem of call admission control in high-speed networks based on the notion of *effective bandwidth*, e.g., [49, 55, 95, 114, 150, 151, 172, 216–218, 406].

In contrast to the well developed field of Markovian queueing models, only few theoretical results exist to date for queueing systems with long-range dependent inputs. For recent work in this area and on the general problem of the relevance of fractal traffic in practice, see [4, 5, 102, 105, 115–117, 121, 122, 138, 146, 184, 199, 258, 318–320, 328, 335, 356]. In this context, see also the discussions in [117, 318, 413] related to some practical experience with the first-generation ATM buffers reported in [79]. While there is considerable scope for future research in the area of queueing models with long-range dependent inputs, queueing in the presence of heavy-tailed service time distributions (and, in general, independent arrivals) is relatively well understood; e.g., see [1, 2, 56, 72, 213, 323, 408]. For specific results relating the behavior of simple queues fed by a single or by many *ON/OFF* sources exhibiting heavy-tailed *ON*- or *OFF*-periods to that of queues with fractional Brownian input streams (as considered in [318]), see for example, [8, 35, 36, 270, 344, 345].

Given the shortage of theoretical results for long-range dependent queueing models, the ability to generate synthetic traces is of particular importance in the context of teletraffic theory and practice. There exist numerous methods to date for generating self-similar traffic traces. Exact methods, which are based on the Durbin-Levinson algorithm [37, 394] are discussed in [24, 146, 196, 198, 394]. They are generally impractical for long time series. Approximate methods are described in [30, 74, 120, 215, 245, 252, 258, 285, 290, 331, 334, 337, 356, 374, 376, 404, 412]; some of these methods rely on earlier results reported in [77, 165, 391], derived for a different purpose and re-interpreted here in the context of synthetic traffic generation. These methods are generally very fast and feasible for even very long time series. However, the statistical quality of the generated sequences is, in general, not well understood [252].

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Bibliography

1. J. Abate, G. L. Choudhury, and W. Whitt. Calculation of the GI/G/1 waiting time distribution and its cumulants from pollaczek's formulas. *Archiv für Elektronik und Übertragungstechnik*, 47:311–321, 1993.
2. J. Abate, G. L. Choudhury, and W. Whitt. Waiting-time tail probabilities in queues with long-tail service-time distributions. *Queueing Systems*, 16:311–338, 1994.
3. P. Abry. *Transformées en ondelettes – Analyses multirésolution et signaux de pression en turbulence*. PhD thesis, Université Claude Bernard, Lyon 1, France, 1994.
4. A. Adas and A. Mukherjee. On resource management and QoS guarantees for long-range dependent traffic. Preprint, 1994.
5. R. Addie, M. Zuckerman, and T. Neame. Fractal traffic: Measurements modelling and performance. Preprint, 1994.
6. R. G. Addie and M. Zuckerman. A Gaussian traffic model for a B-ISDN statistical multiplexer. In *Proceedings of the IEEE Globecom '92*, 1992.
7. C. Agiakloglou and P. Newbold. Lagrange multiplier tests for fractional difference. *Journal of Time Series Analysis*, 15:253–262, 1994.
8. V. Anantharam. On the sojourn time of sessions at an ATM buffer with long-range dependent input traffic. Preprint, University of California, Berkeley, 1995.
9. D. Anick, D. Mitra, and M. M. Sondhi. Stochastic theory of a data-handling system with multiple sources. *Bell System Technical Journal*, 61:1871–1894, 1982.
10. A. A. Anis and E. H. Lloyd. The expected value of the adjusted rescaled Hurst range of independent normal summands. *Biometrika*, 63:111–116, 1976.
11. M. A. Arcones. Limit theorems for non-linear functionals of a stationary Gaussian sequence of vectors. *The Annals of Probability*, 22:2242–2274, 1994.
12. A. Arvidsson and R. Harris. On the performance of some commonly employed models of bursty traffic. Preprint, 1994.
13. A. Astrauskas, J. B. Levy, and M. S. Taqqu. The asymptotic dependence structure of the linear fractional Lévy motion. *Lietuvos Matematikos Rinkinys (Lithuanian Mathematical Journal)*, 31(1):1–28, 1991.

14. R. T. Baillie. Long memory processes and fractional integration in econometrics. *Journal of Econometrics*, 1995. To appear.
15. R. T. Baillie and T. Bollerslev. Cointegration, fractional cointegration, and exchange rate dynamics. *The Journal of Finance*, 49:737–745, 1994.
16. R. T. Baillie, T. Bollerslev, and H. O. Æ. Mikkelsen. Fractionally integrated generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 1995. To appear.
17. R. T. Baillie, C. F. Chung, and M. A. Tieslau. Analyzing inflation by the fractionally integrated ARFIMA-GARCH model. *Journal of Applied Econometrics*, 1995. To appear.
18. R. Ballerini and D. C. Boes. Hurst behavior of shifting level processes. *Water Resources Research*, 21:1642–1648, 1985.
19. L. Bel, G. Oppenheim, L. Robbiano, and M. C. Viano. Densité spectrale, covariance, régularité et propriétés de mélange de processes distributions de type ARMA fractionnaire. Preprint. Journée Longue Portée, Groupe d'Automatique d'Orsay, Paris, May 11 1995.
20. J. Beran. A test of location for data with slowly decaying serial correlations. *Biometrika*, 76:261–269, 1989.
21. J. Beran. A goodness of fit test for time series with long-range dependence. *Journal of the Royal Statistical Society, Series B*, 54:749–760, 1992.
22. J. Beran. Statistical methods for data with long-range dependence. *Statistical Science*, 7(4):404–416, 1992. With discussions and rejoinder, pages 404-427.
23. J. Beran. Maximum likelihood estimation of the differencing parameter for invertible short- and long-memory ARIMA models. *Journal of the Royal Statistical Society, Series B*, 57:659–672, 1995.
24. J. Beran. *Statistics for Long-Memory Processes*. Chapman & Hall, New York, 1994.
25. J. Beran and H. Künsch. Location estimators for processes with long-range dependence. Preprint, 1985.
26. J. Beran, R. Sherman, M. S. Taqqu, and W. Willinger. Long-range dependence in variable-bit-rate video traffic. *IEEE Transactions on Communications*, 43:1566–1579, 1995.
27. J. Beran and N. Terrin. Estimation of the long memory parameter, based on a multivariate Central Limit Theorem. *Journal of Time Series Analysis*, 15:269–278, 1994.
28. L. I. Berge, N. Rakotomalala, J. Feder, and T. Jøssamg. Cross-over in R/S analysis and power spectrum: measurements and simulations. Preprint, 1993.
29. L. M. Berliner. Statistics, probability and chaos. *Statistical Science*, 7(1):69–90, 1992.
30. D. C. Boes. Schemes exhibiting Hurst behavior. In J.N. Srivastava, editor,

Probability and Statistics: Essays in honor of Franklin A. Graybill, pages 21–36, The Netherlands, 1988. Elsevier Science Publishers B.V. (North-Holland).

31. T. Bollerslev and H. O. Æ. Mikkelsen. Modeling and pricing long-memory in stock market volatility. Technical Report 164, Kellogg Graduate School of Management, Northwestern University, 1994. Working paper.
32. V. A. Bolotin. Modeling call holding time distributions for CCS network design and performance analysis. *IEEE Journal of Selected Areas in Communications*, 12(3):433–438, 1994.
33. G. E. P. Box, G. M. Jenkins, and C. Reinsel. *Time Series Analysis: Forecasting and Control.* Prentice Hall, Englewood Cliffs, N.J., third edition, 1994.
34. P. Breuer and P. Major. Central limit theorems for non-linear functionals of Gaussian fields. *Journal of Multivariate Analysis*, 13:425–441, 1983.
35. F. Brichet, J. W. Roberts, A. Simonian, and D. Veitch. Heavy traffic analysis of a fluid queue fed by On/Off with long-range dependence. Technical Report TD(95)03v1, COST 242, 1995.
36. F. Brichet, J. W. Roberts, A. Simonian, and D. Veitch. Heavy traffic analysis of a storage model with long-range dependent On/Off sources. Preprint, 1995.
37. P. J. Brockwell and R. A. Davis. *Time Series: Theory and Methods.* Springer-Verlag, New York, 2nd edition, 1991.
38. K. M. Brothers, W. H. DuMouchel, and A. S. Paulson. Fractiles of the stable laws. Technical report, Rensselaer Polytechnic Institute, Troy, 1983.
39. D. J. Buckle. Bayesian inference for stable distributions. *Journal of the American Statistical Society*, 90(430):605–613, 1995.
40. L. F. Burlaga and L. W. Klein. Fractal structure of the interplanetary magnetic field. *Journal of Geophysical Research*, 91(A1):347–350, 1986.
41. R. Caceres, P. B. Danzig, S. Jamin, and D. J. Mitzel. Characteristics of wide-area TCP/IP conversations. In *Proceedings of the ACM Sigcomm'91*, pages 101–112, 1991.
42. S. Cambanis and I. Fakhre-Zakeri. On prediction of heavy-tailed autoregressive sequences: forward versus reversed time. Technical Report 383, Center for Stochastic Processes at the University of North Carolina, Chapel Hill, 1993.
43. S. Cambanis and S. B. Fotopoulos. On the conditional variance for scale mixtures of normal distributions. Preprint, 1995.
44. S. Cambanis and A. R. Soltani. Prediction of stable processes: spectral and moving average representation. *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete*, 66:593–612, 1984.
45. S. Cambanis and W. Wu. Multiple regression on stable vectors. *Journal of Multivariate Analysis*, 41:243–272, 1992.

46. M. Casdagli. Chaos and deterministic versus stochastic non-linear modeling. *Journal of the Royal Statistical Society, Series B*, 54:303–328, 1991.
47. S. Chatterjee and M. R. Yilmaz. Chaos, fractal and statistics. *Statistical Science*, 7(1):49–68, 1992.
48. G. Chen, B. Abraham, and S. Peiris. Lag window estimation of the degree of differencing in fractionally integrated time series models. *Journal of Time Series Analysi*, 15:473–487, 1994.
49. C. S. Cheng and J. A. Thomas. Effective bandwidth in high-speed digital-networks. *IEEE Journal on Selected Areas in Communications*, 13:1091–1100, 1995.
50. Y-W Cheung. *Long memory in foreign exchange rates and sampling properties of some statistical proceedures related to long memory series.* PhD thesis, University of Pennsylvania, Philadelphia, 1990.
51. Y-W Cheung. Long memory in foreign exchange rates. *Journal of Business and Economic Statistics*, 11:93–101, 1993.
52. Y-W Cheung. Tests for fractional integration: a Monte Carlo investigation. *Journal of Time Series Analysis*, 14:331–345, 1993.
53. Y-W Cheung and F. X. Diebold. On maximum likelihood estimation of the differencing parameter of fractionally-integrated noise with unknown mean. *Journal of Econometrics*, 62:301–316, 1994.
54. Y-W Cheung and K. S. Lai. Do gold market returns have long memory? *The Financial Review*, 28:181–202, 1993.
55. G. L. Choudhury, D. M. Lucantoni, and W. Whitt. On the effectiveness of effective bandwidths for admission control in ATM networks. In J. Labetoulle and J.W. Roberts, editors, *The Fundamental Role of Teletraffic in The Evolution of Tel ecommunications Networks (Proceedings of ITC-14, Antibes Juan-les-Pins, France , June 1994)*, pages 411–420, Amsterdam, 1994. Elsevier.
56. G. L. Choudhury and W. Whitt. Long-tail buffer-content distributions in broadband networks. Preprint, 1995.
57. C. F. Chung and R. T. Baillie. Small sample bias in conditional sum-of-squares estimators of fractionally integrated ARMA models. *Empirical Economics*, 18:791–806, 1993.
58. K. L. Chung and P. Schmidt. The minimum distance estimator for fractionally integrated ARMA models. Preprint, 1995.
59. M. Cinotti, E. Dalle Mese, S. Giordano, and F. Russo. Long-range dependence in Ethernet traffic offered to interconnect DQDB MANs. Preprint, University of Pisa, Italy, 1994.
60. R. Cioczek-Georges and B. B. Mandelbrot. Alternative micropulses and FBM. Preprint, 1994.
61. R. Cioczek-Georges and B. B. Mandelbrot. A class of micropulses and antipersistent fractional Brownian motion. Preprint, 1994.

62. R. Cioczek-Georges, B. B. Mandelbrot, G. Samorodnitsky, and M. S. Taqqu. Stable fractal sums of pulses: the cylindrical case. *Bernoulli*, 1:201–216, 1995.

63. R. Cioczek-Georges and M. S. Taqqu. Does asymptotic linearity of the regression extend to stable domains of attraction? *Journal of Multivariate Analysis*, 48:70–86, 1994.

64. R. Cioczek-Georges and M. S. Taqqu. How do conditional moments of stable vectors depend on the spectral measure? *Stochastic Processes and their Applications*, 54:95–111, 1994.

65. R. Cioczek-Georges and M. S. Taqqu. Sufficient conditions for the existence of conditional moments of stable random variables. Preprint, 1994.

66. R. Cioczek-Georges and M. S. Taqqu. Form of the conditional variance for symmetric stable random variables. *Statistica Sinica*, 5:351–361, 1995.

67. R. Cioczek-Georges and M. S. Taqqu. Necessary conditions for the existence of conditional moments of stable random variables. *Stochastic Processes and their Applications*, 56:233–246, 1995.

68. K. Claffy, H.-W Braun, and G. C. Polyzos. Application of sampling methodologies to network traffic characterization. In *Proceedings of the ACM Sigcomm '93*, pages 194–203, San Francisco, 1993.

69. K. Claffy, H.-W. Braun, and G. C. Polyzos. Tracking long-term growth of the NSFNET backbone. In *Proceedings Infocom '93*, San Francisco, 1993.

70. D. B. H. Cline. Linear prediction of ARMA processes with infinite variance. *Stochastic Processes and their Applications*, 19:281–296, 1985.

71. D. B. H. Cline and P. J. Brockwell. Linear prediction of ARMA processes with infinite variance. *Stochastic Processes and their Applications*, 19:281–296, 1985.

72. J. W. Cohen. Some results on regular variation for distributions in queueing and fluctuation theory. *Journal of Applied Probability*, 10:343–353, 1973.

73. P. Collet and J.-P. Eckmann. Iterated maps on the interval as dynamical systems. In *Progress in Physics I*. Birkhauser, Boston, 1980.

74. F. Comte. Simulation and estimation of long memory continous time models. Technical Report 9410, Centre de Recherche en Economie et Statistique, Institut National de la Statistique et des Etudes Economiques, 1994. Working paper.

75. F. Comte and E. Renault. Long memory continuous time models. Preprint. Journée Longue Portée, Groupe d'Automatique d'Orsay, Paris, May 11 1995.

76. D. R. Cox. Statistical analysis of time series: some recent developments. *Scandinavian Journal of Statistics*, 8:93–115, 1981.

77. D. R. Cox. Long-range dependence: a review. In H.A. David and H.T. David, editors, *Statistics: An Appraisal*, pages 55–74. Iowa State University Press, 1984.

78. M. E. Crovella and A. Bestavros. Self-similarity in world wide web traffic: evidence and possible causes. In *Proceedings of the 1996 ACM SIGMETRICS. International Conference on Measurement and Modeling of Computer Systems*, May 1996. To appear.
79. M. Csenger. Early ATM users lose data. *Communications Week*, May 16 1994.
80. S. Csörgő and J. Mielniczuk. Density estimation under long-range dependence. *The Annals of Statistics*, 23:990–999, 1995.
81. S. Csörgő and J. Mielniczuk. Distant long-range dependent sums and regression estimation. *Stochastic Processes and their Applications*, 59:143–155, 1995.
82. S. Csörgő and J. Mielniczuk. Nonparametic regression under long-range dependent normal errors. *The Annals of Statistics*, 23:1000–1014, 1995.
83. N. J. Cutland, P. E. Kopp, and W. Willinger. Stock price returns and the Joseph effect: a fractional version of the Black-Scholes model. In E. Bolthausen, M. Dozzi, and F. Russo, editors, *Seminar on Stochastic Analysis, Random Fields and Applications*, pages 327–351. Birkhäuser, Boston, 1995.
84. R. Dahlhaus. Efficient parameter estimation for self similar processes. *The Annals of Statistics*, 17(4):1749–1766, 1989.
85. R. Dahlhaus. Efficient location and regression estimation for long range dependent regression models. *The Annals of Statistics*, 23:1029–1047, 1995.
86. R. Dahlhaus and L. Giraitis. The bias and the mean squared error in semi-parametric models for locally stationary time-series. Preprint, 1995.
87. J. Danielsson and C. G. de Vries. Robust tail index and quantile estimation. Preprint. Tinbergen Institute, Rotterdam, The Netherlands, 1995.
88. P. Danzig, S. Jamin, R. Caceres, D. Mitzel, and D. Estrin. An empirical workload model for driving wide-area tcp/ip network simulations. *Internetworking: Research and Experience*, 3:1–26, 1992.
89. R. A. Davis. Gauss-Newton and m-estimation for ARMA processes with infinite variance. Preprint, 1995.
90. R. A. Davis, K. Knight, and J. Liu. M-estimation for autoregressions with infinite variance. *Stochastic Processes and Their Applications*, 40(1):145–180, 1992.
91. R. A. Davis and S. I. Resnick. Tail estimates motivated by extreme value theory. *The Annals of Statistics*, 12:1467–1487, 1984.
92. R. A. Davis and S. I. Resnick. More limit theory for the sample correlation function of moving averages. *Stochastic Processes and the Applications*, 20:257–279, 1985.
93. R. A. Davis and W. Wu. Bootstrapping m-estimates in regression and autoregression with infinite variance. Preprint, 1994.
94. A. C Davison and D. R. Cox. Some simple properties of sums of random

variables having long-range dependence. *Proceedings of the Royal Society London*, A424:255–262, 1989.

95. G. de Veciana, G. Kesidis, and J. Walrand. Resource management in wide-area ATM networks using effective bandwidths. *IEEE Journal on Selected Areas in Communications*, 13:1081–1090, 1995.
96. A. Descloux. Contention probabilities in packet switching networks withstrung input processes. In *Proceedings of the 12th ITC*, Torino, Italy, 1988.
97. R. L. Devaney. *An Introduction to Chaotic Dynamical Systems*. Addison-Wesley, New York, 1989.
98. F. Diebold and G. Rudebusch. Long memory and persistence in aggregate output. *Journal of Monetary Economics*, 24:189–209, 1989.
99. F. Diebold and G. Rudebusch. On the power of Diskery-Fuller tests against fractional alternatives. *Economics Letters*, 35:155–160, 1991.
100. R. L. Dobrushin and P. Major. Non-central limit theorems for non-linear functions of Gaussian fields. *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete*, 50:27–52, 1979.
101. N. G. Duffield. Exponential bounds for queues with markovian arrivals. Preprint, 1993.
102. N. G. Duffield. Economies of scale in queues with sources having power-law large deviation scalings. Preprint, Dublin Institute of Advanced Studies, Dublin, Ireland, DIAS-APG-94-27, 1994.
103. N. G. Duffield, J. T. Lewis, N. O'Connell, R. Russell, and F. Toomey. Statistical issues raised by the Bellcore data. Preprint, 1994.
104. N. G. Duffield, J. T. Lewis, N. O'Connell, R. Russell, and F. Toomey. Entropy of ATM traffic streams: a tool for estimating QoS parameters. *IEEE Journal on Selected Areas in Communications*, 13:981–990, 1995.
105. N. G. Duffield and N. O'Connell. Large deviation and overflow probabilities for the general single-server queue, with applications. *Mathematical Proceedings of the Cambridge Philosophical Society*, 118:363–375, 1995.
106. D. E. Duffy, A. A. Mcintosh, M. Rosenstein, and W. Willinger. Analyzing telecommunications traffic data from working common channel signaling subnetworks. In M. E. Tarter and M. D. Lock, editors, *Statistical Applications of Expanding Computer Facilities*, volume 25, pages 156–165. Interface Foundation of North America, 1993. *Computing Science and Statistics.*
107. D. E. Duffy, A. A. Mcintosh, M. Rosenstein, and W. Willinger. Statistical analysis of CCSN/SS7 traffic data from working CCS subnetworks. *IEEE Journal on Selected Areas in Communications*, 12:544–551, 1994.
108. W. H. DuMouchel. *Stable distributions in statistical inference*. PhD thesis, Univ. Ann Arbor, Univ. Microfilms, Ann Arbor, Mich., 1971.
109. W. H. DuMouchel. On the asymptotic normality of the maximum-likelihood estimate when sampling from a stable distribution. *The Annals*

of Statistics, 1:948–957, 1973.

110. W. H. DuMouchel. Stable distributions in statistical inference: 1.Symmetric stable distributions compared to other long-tailed distributions. *Journal of the American Statistical Association*, 68:469–477, 1973.
111. W. H. DuMouchel. Stable distributions in statistical inference: 2.Information from stably distributed samples. *Journal of the American Statistical Association*, 70:386–393, 1975.
112. W. H. DuMouchel. Estimating the stable index in order to measure tail thickness: a critique. *The Annals of Statistics*, 11:1019–1031, 1983.
113. A. Elwalid, D. P. Heyman, T. V. Lakshman, D. Mitra, and A. Weiss. Fundamental bounds and approximations for ATM multiplexers with applications to video teleconferencing. *IEEE Journal on Selected Areas in Communications*, 13:1004–1016, 1995.
114. A. I. Elwalid and D. Mitra. Effective bandwidth of general Markovian traffic sources and admission control of high-speed networks. *IEEE/ACM Transactions on Networking*, 1(3):329–343, 1993.
115. A. Erramilli, J. Gordon, and W. Willinger. Applications of fractals in engineering for realistic traffic processes. In J. Labetoulle and J.W. Roberts, editors, *The Fundamental Role of Teletraffic in The Evolution of Telecommunications Networks (Proceedings of ITC-14, Antibes Juan-les-Pins, France, June 1994)*, pages 35–44, Amsterdam, 1994. Elsevier.
116. A. Erramilli, D. D. Gosby, and W. Willinger. Engineering for realistic traffic: A fractal analysis of burstiness. In *Proceedings of the Bangalore Regional ITC Seminar, Bangalore, India*, 1993.
117. A. Erramilli, O. Narayan, and W. Willinger. Experimental queueing analysis with long-range dependent packet traffic. *IEEE/ACM Transactions on Networking*, 4:209–223, 1996.
118. A. Erramilli and R. P. Singh. Application of deterministic chaotic maps to characterize broadband traffic. In *Proceedings of the ITC 7th Specialist Seminar, Livingston, NJ*, 1990.
119. A. Erramilli, R. P. Singh, and P. Pruthi. Chaotic maps as models of packet traffic. In J. Labetoulle and J.W. Roberts, editors, *The Fundamental Role of Teletraffic in the Evolution of Telecommunications Networks (Proceedings of ITC-14, Antibes, Juan-les-Pins, France, June 1994)*, pages 329–338, Amsterdam, 1994. Elsevier.
120. A. Erramilli, R. P. Singh, and P. Pruthi. An application of deterministic chaotic maps to model packet traffic. *Queueing Systems*, 20:171–206, 1995.
121. A. Erramilli and J. Wang. Monitoring packet traffic levels. In *Proceedings of the IEEE Globecom '94*, pages 274–280, San Francisco, CA, 1994.
122. A. Erramilli and W. Willinger. Fractal properties in packet traffic measurements. In *Proceedings of the St. Petersburg Regional ITC Seminar, St. Petersburg, Russia*, pages 144–158, 1993.

123. A. Erramilli and W. Willinger. A case for fractal traffic modeling. In *Proceedings of the Australian Telecommunication Networks & Applications Conference 1995*, pages XV–XX, Sydney, Australia, 1995.
124. A. Erramilli, W. Willinger, and P. Pruthi. Fractal traffic flows in high-speed communications networks. *Fractals*, 2(3):409–412, 1994.
125. K. Falconer. *Fractal Geometry: Mathematical Foundations and Applications.* J. Wiley & Sons, New York, 1993.
126. E. Fama. Mandelbrot and the stable Paretian hypothesis. *Journal of Business*, 36:420–429, 1963. Reprinted in *The Random Character of Stock Market Prices*, P. Cootner editor, MIT Press, 1964, pages 297-306.
127. E. Fama. The behavior of stock market prices. *Journal of Business*, 38:34–105, 1965.
128. E. Fama and R. Roll. Some properties of symmetric stable distributions. *Journal of the American Statistical Association*, 63:817–836, 1968.
129. E. Fama and R. Roll. Parameter estimates for symmetric stable distributions. *Journal of the American Statistical Association*, 66:331–338, 1971.
130. J. Feder. *Fractals.* Plenum Press, New York, 1988.
131. W. Feller. The asymptotic distributions of the range of sums of independent random variables. *Annals of Mathematical Statistics*, 22:427–432, 1951.
132. W. Feller. *An Introduction to Probability Theory and its Applications*, volume 2. Wiley, New York, 2nd edition, 1971.
133. K. W. Fendick, V. R. Saksena, and W. Whitt. Dependence in packet queues. *IEEE Transactions on Communications*, 37:1173–1183, 1989.
134. K. W. Fendick, V. R. Saksena, and W. Whitt. Investigating dependence in packet queues with the index of dispersion for work. *IEEE Transactions on Communications*, 39:1231–1244, 1991.
135. P. Flandrin. Wavelet analysis and synthesis of Fractional Brownian motion. *IEEE Transactions on Information Theory*, 38:910–917, 1992.
136. S. B. Fotopoulos and S. Cambanis. Conditional variance for stable random vectors. Technical Report 426, Center for Stochastic Processes at the University of North Carolina, Chapel Hill, 1994.
137. S. B. Fotopoulos and L. He. Form of the conditional variance-covariance matrix for α-stable scale mixtures of normal distributions. Preprint, 1995.
138. H. J. Fowler and W. E. Leland. Local area network traffic characteristics with implications for broadband network congestion management. *IEEE Journal on Selected Areas in Communications*, 9:1139–1149, 1991.
139. R. Fox and M. S. Taqqu. Non-central limit theorems for quadratic forms in random variables having long-range dependence. *The Annals of Probability*, 13:428–446, 1985.
140. R. Fox and M. S. Taqqu. Large-sample properties of parameter estimates for strongly dependent stationary Gaussian time series. *The Annals of Statistics*, 14:517–532, 1986.

141. R. Fox and M. S. Taqqu. Central limit theorems for quadratic forms in random variables having long-range dependence. *Probability Theory and Related Fields*, 24:213–240, 1987.

142. R. Fox and M. S. Taqqu. Multiple stochastic integrals with dependent integrators. *Journal of Multivariate Analysis*, 21:105–127, 1987.

143. A. S. French and L. L. Stockbridge. Fractal and markov behavior in ion channel kinetics. *Can. J. Physiol. Pharm.*, 66:967–970, 1988.

144. V. Frost and B. Melamed. Traffic modeling for telecommunications networks. *IEEE Communications Magazine*, 32:70–80, 1994.

145. M. W. Garrett. *Contributions Toward Real-Time Services on Packet Switched Networks*. PhD thesis, Columbia University, New York, 1993.

146. M. W. Garrett and W. Willinger. Analysis, modeling and generation of self-similar VBR video traffic. In *Proceedings of the ACM Sigcomm '94, London, UK*, pages 269–280, 1994.

147. H. G. Gauch. Prediction, parsimony and noise. *American Scientist*, 81:468–478, 1993.

148. R. Gay and C. C. Heyde. On a class of random field models which allows long range dependence. *Biometrika*, 77:401–403, 1990.

149. J. Geweke and S. Porter-Hudak. The estimation and application of long memory time series models. *Journal of Time Series Analysis*, 4:221–238, 1983.

150. R. J. Gibbens. The statistical analysis of broadband traffic. This volume, 1996.

151. R. J. Gibbens and P. J. Hunt. Effective bandwidths for the multi-type UASchannel. *Queueing Systems*, 9:17–28, 1991.

152. L. Giraitis. Central limit theorem for functionals of a linear process. *Lithuanian Mathematical Journal*, 25:25–35, 1985.

153. L. Giraitis. Central limit theorem for polynomial forms I. *Lithuanian Mathematical Journal*, 29:109–128, 1989.

154. L. Giraitis, H. Koul, and D. Surgailis. Asymptotic normality of regression estimators with long memory errors. *Statistics and Probability Letters*, 1995. To appear.

155. L. Giraitis and R. Leipus. A generalized fractionally differencing approach in long-memory modelling. *Lithuanian Mathematical Journal*, 35:53–65, 1995.

156. L. Giraitis, S. A. Molchanov, and D. Surgailis. Long memory shot noises and limit theorems with application to Burgers' equation. In D. Brillinger, P. Caines, J. Geweke, E. Parzen, M. Rosenblatt, and M. S. Taqqu, editors, *New Directions in Time Series Analysis, Part II*, pages 153–176, New York, 1992. IMA Volumes in Mathematics and its Applications, Volume 46, Springer-Verlag.

157. L. Giraitis, A. Samarov, and P. M. Robinson. Rate optimal semiparametric

estimation of the memory parameter of the Gaussian time series with long range dependence. Technical report, Beiträge für Statistik, Universität Heidelberg, 1995. Technical Report.

158. L. Giraitis and D. Surgailis. Multivariate Appell polynomials and the central limit theorem. In E. Eberlein and M. S. Taqqu, editors, *Dependence in Probability and Statistics*. Birkhauser, New York, 1986.
159. L. Giraitis and D. Surgailis. A central limit theorem for quadratic forms in strongly dependent linear variables and application to asymptotical normality of Whittle's estimate. *Probability Theory and Related Fields*, 86:87–104, 1990.
160. L. Giraitis and D. Surgailis. On shot noise processes with long range dependence. In B. Grigelionis, Y. U. Prohorov, V. V. Sazonov, and V. Statulevičius, editors, *Probability Theory and Mathematical Statistics. Proceedings of the Fifth Vilnius Conference June 25-July 1, 1989*, pages 401–408, Utrecht, the Netherlands, 1990. VSP BV Press. Vol. 1.
161. L. Giraitis and M. S. Taqqu. Limit theorem for bivariate Appell polynomials: Part I. Central limit theorems. Preprint, 1995.
162. L. Giraitis and M. S. Taqqu. Central limit theorems for quadratic forms with time-domain conditions. Preprint, 1996.
163. P. W. Glynn and W. Whitt. Logarithmic asymptotics for steady-state tail probabilities in a single-server queue. *Journal of Applied Probability*, 31:131–156, 1994.
164. V. V. Gorodetskii. On convergence to semi-stable Gaussian processes. *Theory of Probability and its Applications*, 22:498–508, 1977.
165. C. W. J. Granger. Long memory relationships and aggregation of dynamic models. *Journal of Econometrics*, 14:227–238, 1980.
166. C. W. J. Granger and R. Joyeux. An introduction to long-memory time series and fractional differencing. *Journal of Time Series Analysis*, 1:15–30, 1980.
167. M. T. Greene and B. D. Fielitz. Long-term dependence in common stock returns. *Journal of Financial Economics*, 4:339–349, 1977.
168. M. T. Greene and B. D. Fielitz. The effect of long-term dependence on risk return models of common stocks. *Operations Research*, 27:944–951, 1979.
169. G. Gripenberg and I. Norros. On the prediction of fractional Brownian motion. *Journal of Applied Probability*, 1996. To appear.
170. A. Gross. Some mixing conditions for stationary symmetric stable stochastic processes. *Stochastic Processes and their Applications*, 51:277–295, 1994.
171. D. Guégan. *Séries Chronologiques Non Linéaires à Temps Discret*. Statistique Mathématique et Probabilité. Economica, 49, rue Héricart, 75015 Paris, 1994.
172. R. Guerin, H. Admadi, and M. Naghshineh. Equivalent capacity and its

application to bandwidth allocation in high-speed networks. *IEEE Journal on Selected Area Communication*, 9:968–981, 1991.

173. R. Gusella. *A Characterization of the Variability of Packet Arrival Processes in Workstation Networks.* PhD thesis, University of California at Berkeley, Berkeley, CA, 1990.
174. R. Gusella. A measurement study of diskless workstation traffic on an ethernet. *IEEE Transactions Communication*, 38:1557–1568, 1990.
175. R. Gusella. Characterizing the variability of arrival processes with indices of dispersion. *IEEE Journal on Selected Areas in Communications*, 9(2):968–981, 1991.
176. D. Halford. A general mechanical model for $|f|^\alpha$ spectral density random noise with special reference to flicker noise $1/|f|$. *Proceedings of the IEEE*, 56(3):251–258, 1968.
177. F. R. Hampel. Data analysis and self-similar processes. In *Proceedings of the 46th Session of the International Statistical Institute*, Tokyo, Japan, September 1987. International Statistical Institute.
178. F. R. Hampel, E. M. Ronchetti, P. J. Rousseeuv, and W. A. Stahel. *Robust Statistics.* Wiley, New York, 1986.
179. J. Haslett and A. E. Raftery. Space-time modelling with long-memory dependence: assessing Ireland's wind power resource. *Applied Statistics*, 38:1–50, 1989. Includes discussion.
180. H. Heffes and D.M. Lucantoni. A Markov modulated characterization of packetized voice and data traffic and related statistical multiplexer performance. *IEEE Journal on Selected Areas in Communications*, 4:856–868, 1986.
181. S. A. Heimlich. Traffic characterization of the NSFNET national backbone. In *Proceedings of the 1990 Usenix Conference*, pages 207–227, 1990.
182. P. Heinrich. Zero-one laws for polynomials in Gaussian random variables. Preprint, 1995.
183. M. Henry and P. M. Robinson. Bandwidth choice in Gaussian semiparametric estimation of long range dependence. In *Proceedings of the Athens Conference on Applied Probability and Time Series Analysis*, New York, 1996. Springer-Verlag. Time series volume in honour of E. J. Hannan. To appear.
184. C. C. Heyde. Some results on inference for stationary processes and queueing systems. In U. N. Bhatt and I. V. Basawa, editors, *Queueing and Related Models*, pages 337–345, Oxford, UK, 1992. Oxford University Press (Clarendon Press).
185. C. C. Heyde and R. Gay. Smoothed periodogram asymptotics and estimation for processes and fields with possible long-range dependence. *Stochastic Processes and their Applications*, 45:169–182, 1993.
186. D. P. Heyman, A. Tabatabai, and T. V. Lakshman. Statistical analysis and

simulation study of video teleconference traffic in ATM networks. *IEEE Transactions on Circuits and Systems for Video Technology*, 2:49–59, 1992.

187. B. M. Hill. A simple general approach to inference about the tail of a distribution. *The Annals of Statistics*, 3:1163–1174, 1975.
188. H. C. Ho. On limiting distributions of nonlinear functions of noisy Gaussian sequences. *Stochastic Analysis and Applications*, 10:417–430, 1992.
189. H. C. Ho. On central and non-central limit theorems in density estimation for sequences of long-range dependence. Preprint, 1995.
190. H. C. Ho. On the strong uniform consistency of density estimation for strongly dependent sequences. *Statistics & Probability Letters*, 22:149–156, 1995.
191. H. C. Ho and T. Hsing. On the asymptotic expansion of the empirical process of long memory moving averages. Preprint, 1995.
192. H. C. Ho and T. C. Sun. A central limit theorem for non-instantaneous filters of a stationary Gaussian process. *Journal of Multivariate Analysis*, 22:144–155, 1987.
193. H. C. Ho and T. C. Sun. A mixture-type limit theorem for nonlinear functions of Gaussian sequences. *Journal of Theoretical Probability*, 4:407–415, 1991.
194. D. R. Holt and E. L. Crow. Tables and graphs of the stable probability density functions. *Journal of Research of the National Bureau of Standards*, 77B:143–198, 1973.
195. J. R. M. Hosking. Fractional differencing. *Biometrika*, 68(1):165–176, 1981.
196. J. R. M. Hosking. Modeling persistence in hydrological time series using fractional differencing. *Water Resources Research*, 20:1898–1908, 1984.
197. J. R. M. Hosking. Asymptotic distributions of the sample mean, autocovariances and autocorrelations of long-memory time series. *Journal of Econometrics*, 1995. To appear.
198. C. Huang, M. Devetsikiotis, I. Lambadaris, and A. R. Kaye. Fast simulation for self-similar traffic in ATM networks. In *Proceedings of the ICC '95*, pages 438–444, Seattle, WA, 1995.
199. C. Huang, M. Devetsikiotis, I. Lambadaris, and A. R. Kaye. Modeling and simulation of self-similar variable bit rate compressed video: A unified approach. *Computer Communications Review*, 25:114–125, 1995. Proceedings of the ACM/SIGCOMM'95, Cambridge, MA, August 1995.
200. H. E. Hurst. Long-term storage capacity of reservoirs. *Transactions of the American Society of Civil Engineers*, 116:770–808, 1951.
201. H. E. Hurst. Methods of using long-term storage in reservoirs. *Proceedings of the Institution of Civil Engineers, Part I*, pages 519–577, 1955.
202. H. E. Hurst, R. P. Black, and Y. M. Simaika. *Long-Term Storage: An Experimental Study*. Constable, London, 1965.
203. C. M. Hurvich and K. I. Beltrao. Asymptotics for the low-frequency ordi-

nates of the periodogram of a long-memory time series. *Journal of Time Series Analysis*, 14:455–472, 1993.

204. C. M. Hurvich and K. I. Beltrao. Automatic semiparametric estimation of the memory parameter of a long memory time series. *Journal of Time Series Analysis*, 15:285–302, 1994.
205. C. M. Hurvich and B. K. Ray. Estimation of the long-memory parameter for nonstationary or noninvertible fractionally integrated processes. *Journal of Time Series Analysis*, 16:17–41, 1995.
206. C.M. Hurvich, R. Deo, and J. Brodsky. The mean squared error of Geweke and Porter-Hudak's estimator of the memory parameter of a long memory time series. Preprint, 1995.
207. C. L. Hwang and S. Q. Li. On input state space reduction and buffer noneffective region. In *Proceedings of IEEE Infocom '94*, pages 1018–1028, 1994.
208. A. V. Ivanov and N. N. Leonenko. *Statistical Analysis of Random Fields.* Kluwer Academic Publishers, Dordrecht/Boston/London, 1989. Translated from the Russian, 1986 edition.
209. D. L. Jagerman, B. Melamed, and W. Willinger. Stochastic modeling of traffic processes. In J. Dshalalow, editor, *Frontiers in Queueing: Models, Methods and Problems.* CRC Press, 1996. To appear.
210. R. Jain and S. A. Routhier. Packet trains: Measurements and a new model for computer network traffic. *IEEE Journal on Selected Areas in Communications*, 4:986–995, 1986.
211. A. Janicki and A. Weron. *Simulation and Chaotic Behavior of α-stable Stochastic Processes.* Marcel Dekker, New York, 1994.
212. W. H. Jefferys and J. O. Berger. Ockham's razor and Bayesian analysis. *American Scientist*, 80:64–72, 1992.
213. P. R. Jelenkovic and A. A. Lazar. Subexponential asymptotics of a network multiplexer. Preprint, CTR, Columbia University, New York, 1995.
214. C. Jimenez, K. Hipel, and A. I. McLeod. Developments in modelling long term persistence. Preprint, 1988.
215. N. J. Kasdin. Discrete simulation of colored noise and stochastic processes and $1/f^\alpha$ power law noise generation. *Proceedings of the IEEE*, 83(5):802–827, 1995.
216. F. P. Kelly. Effective bandwidths at multi-class queues. *Queueing Systems*, 9:5–15, 1991.
217. F. P. Kelly. Notes on effective bandwidths. This volume, 1996.
218. G. Kesidis, J. Walrand, and C. S. Chang. Effective bandwidths for multi-class Markov fluids and other ATM sources. *IEEE/ACM Transactions on Networking*, 1:424–428, 1993.
219. V. Klemeš. The Hurst phenomenon: a puzzle? *Water Resources Research*, 10:675–688, 1974.

220. S. Klivansky, A. Mukherjee, and C. Song. Factors contributing to self-similarity over nsfnet. Preprint, Georgia Institute of Technology, 1994.

221. C. Klüppelberg and T. Mikosch. Spectral estimates and stable processes. *Stochastic Processes and their Applications*, 47:323–344, 1993.

222. C. Klüppelberg and T. Mikosch. Some limit theory for the self-normalized periodogram of stable processes. *Scandinavian Journal of Statistics*, 21:485–492, 1994.

223. C. Klüppelberg and T. Mikosch. The integrated periodogram for stable processes. *The Annals of Statistics*, 1995. To appear.

224. C. Klüppelberg and T. Mikosch. Self-normalized and randomly centered spectral estimates. In *Proceedings of the Athens Conference on Applied Probability and Time Series Analysis*, New York, 1996. Springer-Verlag. Time series volume in honour of E. J. Hannan. To appear.

225. S. M. Kogon and D. G. Manolakis. Infrared scene modeling and interpolation using fractional Lévy stable motion. *Fractals*, 2(6):303–306, 1994.

226. S. M. Kogon and D. G. Manolakis. Fractal-based modeling interpolation of non-Gaussian images. Preprint. Presented at SPIE: Visual Communications and Image Processing '94, Chicago, IL, 1995.

227. S. M. Kogon and D. G. Manolakis. Linear parametric models for signals with long-range dependence and infinite variance. Preprint. Submitted to ICASSP95, 1995.

228. P. Kokoszka and T. Mikosch. The integrated periodogram for long-memory processes with finite or infinite variance. Preprint, 1995.

229. P. S. Kokoszka. Prediction of infinite variance fractional ARIMA. *Probability and Mathematical Statistics*, 16, 1995. To appear.

230. P. S. Kokoszka and M. S. Taqqu. Asymptotic dependence of stable self-similar processes of Chentsov type. In R. M. Dudley, M. G. Hahn, and J. Kuelbs, editors, *Probability in Banach Spaces, 8: Proceedings of the Eighth International Conference*, pages 152–165, Boston, 1992. Birkhäuser.

231. P. S. Kokoszka and M. S. Taqqu. Asymptotic dependence of moving average type self-similar stable random fields. *Nagoya Mathematical Journal*, 130:85–100, 1993.

232. P. S. Kokoszka and M. S. Taqqu. Infinite variance stable ARMA processes. *Journal of Time Series Analysis*, 15:203–220, 1994.

233. P. S. Kokoszka and M. S. Taqqu. New classes of self-similar symmetric stable random fields. *Journal of Theoretical Probability*, 7:527–549, 1994.

234. P. S. Kokoszka and M. S. Taqqu. Discrete time parametric models with long memory and infinite variance. Preprint, 1995.

235. P. S. Kokoszka and M. S. Taqqu. Fractional ARIMA with stable innovations. *Stochastic Processes and their Applications*, 60:19–47, 1995.

236. P. S. Kokoszka and M. S. Taqqu. The asymptotic behavior of quadratic forms in heavy-tailed strongly dependent random variables. *Stochastic*

Processes and their Applications, 1996. To appear.

237. P. S. Kokoszka and M. S. Taqqu. Infinite variance stable moving averages with long memory. *Journal of Econometrics*, 73, 1996. To appear.
238. P. S. Kokoszka and M. S. Taqqu. Parameter estimation for infinite variance fractional ARIMA. To appear in *The Annals of Statistics*, 1996.
239. A. N. Kolmogorov. Local structure of turbulence in an incompressible liquid for very large Reynolds numbers. *Comptes Rendus (Doklady) de l'Académie des Sciences de l' URSS (N.S.)*, 30:299–303, 1941. Reprinted in S. K. Friedlander and L. Topper *Turbulence: classic papers on statistical theory*, Interscience, New York, 1961.
240. T. Konstantopoulos and V. Anantharam. Optimal flow control schemes that regulate the burstiness of traffic. *IEEE/ACM Transactions on Networking*, 3:423–432, 1995.
241. H. L. Koul and K. Mukherjee. Asymptotics of R-, MD- and LAD-estimators in linear regression models with long range dependent errors. *Probability Theory and Related Fields*, 95:535–553, 1993.
242. I. A. Koutrouvelis. Regression-type estimation of the parameters of stable laws. *Journal of the American Statistical Association*, 75:918–928, 1980.
243. I. A. Koutrouvelis. An iterative procedure for the estimation of the parameters of the stable law. *Communication in Statistics-Simulation and Computation*, 10:17–28, 1981.
244. M. Kratz and S. I. Resnick. The qq-estimator and heavy tails. Preprint, School of ORIE, Cornell University, Ithaca, NY, 1995.
245. W. M. Kruger, S. D. Jost, and U. Axen. On synthesizing discrete fractional Brownian motion. Preprint, 1992.
246. H. Künsch. Statistical aspects of self-similar processes. *Proceedings of the First World Congress of the Bernoulli Society*, 1:67–74, 1987.
247. H. Künsch, J. Beran, and F. Hampel. Contrasts under long-range correlations. *The Annals of Statistics*, 21:943–964, 1993.
248. T. G. Kurtz. Limit theorems for workload input models. This volume, 1996.
249. G. Lang and J-M. Azaïs. Nonparametric estimation of the strong dependence exponent for Gaussian processes. Preprint. Journée Longue Portée, Groupe d'Automatique d'Orsay, Paris, May 11 1995.
250. A. Lasota and M. C. Mackey. *Chaos, Fractals, and Noise – Stochastic Aspects of Dynamics.* Springer-Verlag, New York, 1994.
251. G. Latouche and V. Ramaswami. A logarithmic reduction algorithm for quasi birth and death processes. *Journal of Applied Probability*, 30:650–674, 1993.
252. W.-C. Lau, A. Erramilli, J. L. Wang, and W. Willinger. Self-similar traffic generation: The random midpoint displacement algorithm and its properties. In *Proceedings of the ICC '95*, pages 466–472, Seattle, WA, 1995.

253. W.-C. Lau, A. Erramilli, J. L. Wang, and W. Willinger. Self-similar traffic parameter estimation: a semi-parametric periodogram-based algorithm. In *Proceedings of the IEEE Globecom '95*, pages 2225–2231, Singapore, 1995.

254. A. J. Lawrence and N. T. Kottegoda. Stochastic modelling of riverflow time series. *Journal of the Royal Statistical Society*, A 140,(1):1–47, 1977.

255. W. E. Leland. LAN traffic behavior from milliseconds to days. In *Proceedings of the ITC 7th Specialist Seminar*, Morristown, N.J., 1990.

256. W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson. On the self-similar nature of Ethernet traffic. *Computer Communications Review*, 23:183–193, 1993. Proceedings of the ACM/SIGCOMM'93, San Francisco, September 1993. Reprinted in *Trends in Networking – Internet*, the conference book of the Spring 1995 Conference of the National Unix User Group of the Netherlands (NLUUG). Also reprinted in *Computer Communication Review*, **25**, Nb. 1 (1995), 202-212, a special anniversary issue devoted to "Highlights from 25 years of the Computer Communications Review".

257. W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson. Statistical analysis of high time-resolution Ethernet LAN traffic measurements. In M. E. Tarter and M. D. Lock, editors, *Statistical Applications of Expanding Computer Facilities*, volume 25, pages 146–155. Interface Foundation of North America, 1993. *Computing Science and Statistics.*

258. W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson. On the self-similar nature of Ethernet traffic (Extended version). *IEEE/ACM Transactions on Networking*, 2:1–15, 1994.

259. W. E. Leland, W. Willinger, M. S. Taqqu, and D. V. Wilson. Statistical analysis and stochastic modeling of self-similar data traffic. In J. Labetoulle and J. W. Roberts, editors, *The Fundamental Role of Teletraffic in the Evolution of Telecommunications Networks*, pages 319–328, Amsterdam, 1994. Proceedings of the 14th International Teletraffic Congress (ITC '94), Elsevier Science B.V.

260. W. E. Leland and D. V. Wilson. High time-resolution measurement and analysis of LAN traffic: Implications for LAN interconnection. In *Proceedings of the Infocom '91*, pages 1360–1366, Bal Harbour, FL, 1991.

261. J. Levy and M. S. Taqqu. On renewal processes having stable inter-renewal intervals and stable rewards. *Les Annales des Sciences Mathematiques du Quebec*, 11:95–110, 1987.

262. J. B. Levy and M. S. Taqqu. A characterization of the asymptotic behavior of stationary stable processes. In S. Cambanis, G. Samorodnitsky, and M. S. Taqqu, editors, *Stable Processes and Related Topics*, volume 25 of *Progress in Probability*, pages 181–198, Boston, 1991. Birkhäuser.

263. S. Q. Li, S. Chong, and C. L. Hwang. Link capacity allocation and network control by filtered input rate in high-speed networks. *IEEE/ACM Transactions on Networking*, 3:10–25, 1995.

264. S. Q. Li and C. L. Hwang. Queue response to input correlation functions

continuous spectral analysis. *IEEE/ACM Transactions on Networking*, 1:678–692, 1993.

265. S. Q. Li and C. L. Hwang. Queue response to input correlation functions: Discrete spectral analysis. *IEEE/ACM Transactions on Networking*, 1:522–533, 1993.
266. L. S. Liebovitch. Testing fractal and markov models of ion channel kinetics. *Biophysics Journal*, 55:373–377, 1989.
267. L. S. Liebovitch, J. Fischbarg, and J. P. Koniarek. Ion channel kinetics: a model based on fractal scaling rather than markov processes. *Mathematical Biosciences*, 84:37–68, 1987.
268. L. S. Liebovitch, J. Fischbarg, J. P. Koniarek, I. Todorova, and M. Wang. Fractal model of ion-channel kinetics. *Biochim. Biophys. Acta.*, 896:173–180, 1987.
269. L. S. Liebovitch and J. M. Sullivan. Fractal analysis of a voltage-dependent potassium channel from cultured mouse hippocampal neurons. *Biophysics Journal*, 52:979–988, 1987.
270. N. Likhanov, B. Tsybakov, and N. D. Georganas. Analysis of an ATM buffer with self-similar ("fractal") input traffic. In *Proceedings of the IEEE Infocom '95*, pages 985–992, Boston, MA, 1995.
271. M. Livny, B. Melamed, and A. K. Tsiolis. The impact of autocorrelation on queueing systems. *Management Science*, 39:322–339, 1993.
272. E. H. Lloyd and D. Warren. The discrete Hurst range for skew independent two-valued inflows. *Stochastic Hydrology and Hydraulics*, 1:53–66, 1987.
273. A. W. Lo. Long-term memory in stock market prices. *Econometrica*, 59:1279–1313, 1991.
274. S. B. Lowen and M. C. Teich. Power-law shot noise. *IEEE Transactions on Information Theory*, IT-36(6):1302–1318, 1990.
275. S. B. Lowen and M. C. Teich. Doubly stochastic Poisson point process driven by fractal shot noise. *Physical Review A*, 43:4192–4215, 1991.
276. S. B. Lowen and M. C. Teich. Fractal renewal processes generate $1/f$ noise. *Physical Review E*, 47:992–1001, 1993.
277. D. M. Lucantoni. The BMAP/G/1 queue. In L. Donatiello and R. Nelson, editors, *Models and Techniques for Performance Evaluation of Computer and Communication Systems*, pages 330–358. Springer-Verlag, New York, 1993. Lecture Notes in Computer Science.
278. C. Ludena. Estimation of integrals with respect to the logarithm of the spectral density of stationary Gaussian processes with long range dependence. Preprint. Journée Longue Portée, Groupe d'Automatique d'Orsay, Paris, May 11 1995.
279. T. Lundahl, W. J. Ohley, S. M. Kay, and R. Siffert. Fractional Brownian motion: A maximum likelihood estimator and its application to image texture. *IEEE Transactions on Pattern Analysis and Machine Intelligence*,

MI-5(3):152–161, 1986.

280. P. Major. *Multiple Wiener-Itô Integrals*, volume 849 of *Springer Lecture Notes in Mathematics*. Springer-Verlag, New York, 1981.
281. B. B. Mandelbrot. The Pareto-Lévy law and the distribution of income. *International Economic Review*, 1:79–106, 1960.
282. B. B. Mandelbrot. The variation of certain speculative prices. *Journal of Business*, 36:394–419, 1963. Reprinted in *The Random Character of Stock Market Prices*, P. Cootner editor, MIT Press, 1964, pages 307-332.
283. B. B. Mandelbrot. Self-similar error clusters in communications systems and the concept of conditional systems and the concept of conditional stationarity. *IEEE Transactions on Communications Technology*, COM-13:71–90, 1965.
284. B. B. Mandelbrot. Long-run linearity, locally Gaussian processes, H-spectra and infinite variances. *International Economic Review*, 10:82–113, 1969.
285. B. B. Mandelbrot. A fast fractional Gaussian noise generator. *Water Resources Research*, 7:543–553, 1971.
286. B. B. Mandelbrot. Limit theorems on the self-normalized range for weakly and strongly dependent processes. *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete*, 31:271–285, 1975.
287. B. B. Mandelbrot. *The Fractal Geometry of Nature*. W.H. Freeman and Co., San Francisco, 1982.
288. B. B. Mandelbrot and M. S. Taqqu. Robust R/S analysis of long-run serial correlation. In *Proceedings of the 42nd Session of the International Statistical Institute*, Manila, 1979. Bulletin of the International Statistical Institute. Vol.48, Book 2, pp. 69-104.
289. B. B. Mandelbrot and J. W. Van Ness. Fractional Brownian motions, fractional noises and applications. *SIAM Review*, 10:422–437, 1968.
290. B .B. Mandelbrot and J. R. Wallis. Computer experiments with fractional Gaussian noises, Parts 1,2,3˙ *Water Resources Research*, 5:228–267, 1969.
291. B. B. Mandelbrot and J. R. Wallis. Robustness of the rescaled range R/S in the measurement of noncyclic long-run statistical dependence. *Water Resources Research*, 5:967–988, 1969.
292. B. B. Mandelbrot and J. R. Wallis. Some long-run properties of geophysical records. *Water Resources Research*, 5:321–340, 1969.
293. W. T. Marshall and S. P. Morgan. Statistics of mixed data traffic on a local area network. *Computer Networks and ISDN Systems*, 10:185–194, 1985.
294. E. Masry. The wavelet transform of stochastic processes with stationary increments and its application to fractional Brownian motion. *IEEE Transactions on Information Theory*, 39(1):260–264, 1993.
295. J. H. McCulloch. Simple consistent estimators of stable distribution pa-

rameters. *Communications in Statistics-Computation and Simulation*, 15:1109–1136, 1986.

296. J. H. McCulloch. Numerical approximation of the symmetric stable distribution and density. Preprint, 1994.
297. J. H. McCulloch. Financial applications of stable distributions. In G. S. Maddala and C. R. Rao, editors, *Statistical Methods in Finance.* Volume 14 of *Handbook of Statistics.* Elsevier Science, 1996. To appear.
298. J. H. McCulloch. Measuring tail thickness in order to estimate the stable index α: a critique. *Journal of Business and Economic Statistics*, 1996. To appear.
299. J. H. McCulloch, J. P. Nolan, and A. K. Panorska. Estimation of stable spectral measures. Preprint, 1996.
300. J. H. McCulloch and D. B. Panton. Precise tabulation of the maximally-skewed stable distributions and densities. *Computational Statistics and Data Analysis*, 1996. To appear.
301. A. A. Mcintosh. Analyzing telephone network data. Preprint, 1995.
302. A. I. McLeod and K.W. Hipel. Preservation of the rescaled adjusted range, Parts 1,2,3˙ *Water Resources Research*, 14:491–518, 1978.
303. O. B. McManus, D. S. Weiss, C. E. Spivak, A. L. Blatz, and K. L. Magleby. Fractal models are inadequate for the kinetics of four different ion channels. *Biophys. J.*, 54:859–870, 1988.
304. K. Meier-Hellstern, P. E. Wirth, Y-L Yan, and D. A. Hoeflin. Traffic models for ISDN data users: office automation application. In A. Jensen and V. B. Iversen, editors, *Teletraffic and Datatraffic in a Period of Change (Proceedings of ITC-13, Copenhagen, Denmark)*, pages 167–172. North Holland, Amsterdam, 1991.
305. B. Melamed. An overview of TES processes and modeling methodology. In L. Donatiello and R. Nelson, editors, *Models and techniques for Performance Evaluation of Computer and Communications Systems*, pages 359–393. Springer-Verlag, New York, 1993. Lecture Notes in Computer Science.
306. T. Mikosch, T. Gadrich, C. Klüppelberg, and R. J. Adler. Parameter estimation for ARMA models with infinite variance innovations. *The Annals of Statistics*, 23:305–326, 1995.
307. S. Mittnik and S. T. Rachev. Stable distributions for asset returns. *Applied Mathematics Letters*, 2:301–304, 1989.
308. S. Mittnik and S. T. Rachev. Alternative multivariate stable distributions and their applications to financial modeling. In S. Cambanis, G. Samorodnitsky, and M. S. Taqqu, editors, *Stable Processes and Related Topics*, volume 25 of *Progress in Probability*, pages 107–119. Birkhäuser, Boston, 1991.
309. S. Mittnik and S. T. Rachev. Modeling asset returns with alternative stable

distributions. *Econometric Review*, 12:261–330, 1993.

310. A. Montanari, R. Rosso, and M. S. Taqqu. Fractionally differenced ARIMA models applied to hydrologic time series: identification, estimation and simulation. Preprint, 1995.
311. A. Montanari, R. Rosso, and M. S. Taqqu. A seasonal fractionally different ARIMA model: an application to the Nile River monthly flows at Aswan. Preprint, 1995.
312. A. Montanari, R. Rosso, and M. S. Taqqu. Some long-run properties of rainfall records in Italy. Preprint, 1995.
313. E. W. Montroll and M. F. Shlesinger. On 1/f noise and other distributions with long tails. *Proceedings of the National Academy of Sciences of the USA*, 79:3380–3383, 1982.
314. A. Mukherjee. On the dynamics and significance of low frequency components of internet load. Preprint, 1992.
315. D. K. Nassiuma. Symmetric stable sequences with missing observations. *Journal of Time Series Analysis*, 15:313–323, 1994.
316. M. F. Neuts. A versatile Markovian point process. *Journal of Applied Probability*, 18:764–779, 1979.
317. M. F. Neuts. *Structured Stochastic Matrices of M/G/1 Type and Their Applications.* Marcel Dekker, New York, 1989.
318. I. Norros. A storage model with self-similar input. *Queueing Systems And Their Applications*, 16:387–396, 1994.
319. I. Norros. On the use of fractional Brownian motion in the theory of connectionless networks. *IEEE Journal on Selected Areas in Communications*, 13:953–962, 1995.
320. I. Norros, A. Simonian, D. Veitch, and J. Virtamo. A Beneš formula for the fractional Brownian storage. Technical Report TD(95)004v2, COST 242, 1995.
321. J. Nowicka and A. Weron. Numerical approximation of dependence structure for symmetric stable AR(2) processes. Preprint, 1995.
322. S. Painter and L. Paterson. Fractional Lévy motion as a model for spatial variability in sedimentary rock. *Geophysical Research Letters*, 21(25):2857–2860, 1994.
323. A. G. Pakes. On the tails of waiting-time distributions. *Journal of Applied Probability*, 12:555–564, 1975.
324. D. B. Panton. Cumulative distribution function values for symmetric standardized stable distributions. *Communication in Statistics-Simulation and Computation*, 21:485–492, 1992.
325. D. B. Panton. Distribution function values for logstable distributions. *Computers and Mathematics with Applications*, 9:17–24, 1993.
326. K. Park, G. Kim, and M. Crovella. On the cause and effect of self-similar network traffic. Boston University preprint, 1996.

327. C. Partridge. The end of simple traffic models. *IEEE Network*, September 1993. Editor's Note.

328. M. Parulekar and A. M. Makowski. Buffer overflow probabilities for a multiplexer with self-similar traffic. Preprint, University of Maryland, College Park, MD, 1995.

329. P. F. Pawlita. Traffic measurements in data networks, recent measurement results, and some implications. *IEEE Transactions of Communication COM-29*, pages 525–535, 1981.

330. P. F. Pawlita. Two decades of data traffic measurements: A survey of published results, experiences and applicability. In *Proceedings of the 12th ITC*, Torino, Italy, 1988.

331. V. Paxon and S. Floyd. Wide-area traffic: The failure of poisson modeling. In *Proceedings of the ACM Sigcomm '94*, pages 257–268, London, UK, 1994.

332. V. Paxson. Empirically derived analytic models of wide-area TCP connections. *IEEE/ACM Transactions on Networking*, 2(4):316–336, 1994.

333. V. Paxson. Growth trends in wide-area TCP connections. *IEEE Network*, pages 8–17, July/August 1994.

334. V. Paxson. Fast approximation of self-similar network traffic. Preprint, 1995.

335. V. Paxson and S. Floyd. Wide area traffic: The failure of poisson modeling. *IEEE/ACM Transactions on Networking*, 3:226–244, 1995.

336. M. S. Peiris and B. J. C. Perera. On prediction with fractionally differenced ARIMA models. *Journal of Time Series Analysis*, 9:215–220, 1988.

337. H.-O. Peitgen, H. Juergens, and D. Saupe. *Chaos and Fractals: New Frontiers of Science*. Springer-Verlag, New York, 1992.

338. H.-O. Peitgen and D. Saupe, editors. *The Science of Fractal Images*. Springer-Verlag, New York, 1988.

339. C.-K. Peng, S. V. Buldyrev, A. L. Goldberger, S. Havlin, F. Sciortino, M. Simons, and H. E. Stanley. Long-range correlations in nucleotide sequences. *Nature*, 356:168–170, 1992.

340. C.-K. Peng, S. Havlin, H. E. Stanley, and A. L. Goldberger. Quantification of scaling exponents and crossover phenomena in nonstationary heartbeat time series. *Chaos*, 5:82–87, 1995.

341. A. P. Pentland. Fractal-based description of natural scenes. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, PAMI-6(4):661–674, 1984.

342. E. E. Peters. *Chaos and Order in the Capital Market*. Wiley, New York, 1991.

343. M. B. Priestley and T. S. Rao. A test for non-stationarity of time-series. *Journal of the Royal Statistical Society, Series B*, 31:140–149, 1969.

344. P. Pruthi. *An application of chaotic maps to packet traffic modeling.*

PhD thesis, Royal Institute of Technology, Stockholm, Stockholm, Sweden, 1995.

345. P. Pruthi and A. Erramilli. Heavy-tailed on/off source behavior and self-similar traffic. In *Proceedings of the ICC '95*, pages 445–450, Seattle, WA, 1995.

346. K. E. E. Raatikainen. Symptoms of self-similarity in measured arrival process of ethernet packets to a file server. Technical Report Series of Publications C-1994-4, University of Helsinki, Dept. of Computer Science, 1994.

347. S. T. Rachev and G. Samorodnitsky. Option pricing formulae for speculative prices modelled by subordinated stochastic processes. *Serdica*, 19:175–190, 1993.

348. V. Ramaswami. Traffic performance modeling for packet communications: Whence where and whither? In *Proceedings of the 3rd Australian Teletraffic Seminar*, Adelaide, Australia, 1988.

349. V. Ramaswami and G. Latouche. Modeling packet arrivals from asynchronous input lines. In *Proceedings of the 12th ITC*, Torino, Italy, 1988.

350. V. Ramaswami, M. Rumsewicz, W. Willinger, and T. Eliazov. Comparison of some traffic models for ATM performance studies. In A. Jensen and V. B. Iversen, editors, *Teletraffic and Datatraffic in a Period of Change (Proceedings of ITC-13, Copenhagen, Denmark)*, pages 7–12. North Holland, Amsterdam, 1991.

351. V. Ramaswami and W. Willinger. Efficient traffic performance strategies for packet multiplexers. *Computer Networks and ISDN Systems*, 20:401–407, 1990.

352. B. K. Ray. Modeling long-memory processes for optimal long-range prediction. *Journal of Time Series Analysis*, 14(5):511–525, 1993.

353. V. A. Reisen. Estimation of the fractional difference parameter in the ARIMA (p, d, q) model using the smoothed periodogram. *Journal of Time Series Analysis*, 15:335–350, 1994.

354. S. Resnick and C. Starica. Consistency of Hill's estimator for dependent data. *Journal of Applied Probability*, 32:139–167, 1995.

355. S. I. Resnick. Heavy tail modeling and teletraffic data. Preprint, School of ORIE, Cornell University, Ithaca, NY, 1995.

356. S. I. Resnick and G. Samorodnitsky. Performance decay in a single server exponential queueing model with long range dependence. *Operations Research*, 1995. to appear.

357. P. M. Robinson. Automatic frequency domain inference on semiparametric and nonparametric models. *Econmetrica*, 59:1329–1363, 1991.

358. P. M. Robinson. Nonparametric function estimation for long memory time series. In W.A. Barnett, J. Powell, and G.E. Tauchen, editors, *Nonparametric and Semiparametric Methods in Econometrics and Statistics: Pro-*

ceedings of the Fifth International Symposium in Economic Theory and Econometrics, pages 437–457. Cambridge University Press, 1991.

359. P. M. Robinson. Efficient tests of nonstationarity hypotheses. *Journal of the American Statistical Association*, 89:1420–1437, 1994.
360. P. M. Robinson. Rates of convergence and optimal bandwidth in spectral analysis of processes with long range dependence. *Probability Theory and Related Fields*, 99:443–473, 1994.
361. P. M. Robinson. Semiparametric analysis of long-memory time series. *The Annals of Statistics*, 22:515–539, 1994.
362. P. M. Robinson. *Time series with strong dependence*, volume 1 of *Advances in Econometrics. Sixth World Congress.*, chapter 2, pages 47–95. Cambridge University Press, 1994.
363. P. M. Robinson. Gaussian semiparametric estimation of long range dependence. *The Annals of Statistics*, 23:1630–1661, 1995.
364. P. M. Robinson. Log-periodogram regression of time series with long range dependence. *The Annals of Statistics*, 23:1048–1072, 1995.
365. P. M. Robinson and F. J. Hidalgo. Time series regression with long range dependence. Preprint, 1995.
366. P. M. Robinson and C. Velasco. Autocorrelation – robust inference. To appear In *Hanbook of Statistics. Volume on Robust Inference*, 1995.
367. J. Rosiński and T. Żak. The equivalence of ergodicity and weak mixing for infinitely divisible processes. Preprint, 1995.
368. J. Rosiński and T. Żak. Simple conditions for mixing of infinitely divisible processes. Preprint, 1995.
369. B. K. Ryu and S. B. Lowen. Modeling self-similar traffic using the fractal-shot-noise-driven-poisson-process. Preprint, 1994.
370. A. Samarov and M. S. Taqqu. On the efficiency of the sample mean in long memory noise. *Journal of Time Series Analysis*, 9:191–200, 1988.
371. G. Samorodnitsky. A class of shot noise models for financial applications. Preprint, 1995.
372. G. Samorodnitsky and M. S. Taqqu. The various linear fractional Lévy motions. In T. W. Anderson, K. B. Athreya, and D. L. Iglehart, editors, *Probability, Statistics and Mathematics: Papers in Honor of Samuel Karlin*, pages 261–270, Boston, 1989. Academic Press.
373. G. Samorodnitsky and M. S. Taqqu. Linear models with long-range dependence and finite or infinite variance. In D. Brillinger, P. Caines, J. Geweke, E. Parzen, M. Rosenblatt, and M. S. Taqqu, editors, *New Directions in Time Series Analysis, Part II*, pages 325–340, New York, 1992. IMA Volumes in Mathematics and its Applications, Volume 46, Springer-Verlag.
374. G. Samorodnitsky and M. S. Taqqu. *Stable Non-Gaussian Processes: Stochastic Models with Infinite Variance.* Chapman and Hall, New York, London, 1994.

375. M. V. Sanchez de Naranjo. Central limit theorem for non-linear functionals of stationary vector Gaussian process. Preprint, 1994.

376. D. Saupe. Algorithm for random fractals. In H.-O. Peitgen and D. Saupe, editors, *The Science of Fractal Images*, chapter 2, pages 71–113. Springer-Verlag, New York, 1988.

377. H. G. Schuster. *Deterministic Chaos: An Introduction*. VCH, New York, 1988. 2nd Edition.

378. J. F. Shoch and J. A. Hupp. Measured performance of an ethernet local network. *Communicataions of the ACM*, 23(12):711–721, 1980.

379. E. Slud. Some applications of counting process models with partially observed covariates. Preprint, 1995.

380. R. L. Smith. Estimating tails of probability distributions. *The Annals of Statistics*, 15:1174–1207, 1987.

381. F. B. Sowell. The fractional unit-root distribution. *Econometrica*, 58:495–505, 1990.

382. F. B. Sowell. Maximum likelihood estimation of stationary univariate fractionally integrated time series models. *Journal of Econometrics*, 53:165–188, 1992.

383. F. B. Sowell. Modeling long run behavior with the fractional ARIMA model. *Journal of Monetary Economics*, 29:277–302, 1992.

384. K. Sriram and W. Whitt. Characterizing superposition arrival processes in packet multiplexers for voice and data. *IEEE Journal on Selected Areas in Communications*, 4:833–846, 1989.

385. D. Surgailis. On Poisson multiple stochastic integral and associated equilibrium Markov process. In *Theory and Applications of Random Fields*, pages 233–238. Springer-Verlag, Berlin, 1983. In: *Lecture Notes in Control and Information Science*, Vol. **49**.

386. H. Takayasu. $f^{-\beta}$ power spectrum and stable distribution. *Journal of the Physical Society of Japan*, 56(4):1257–1260, 1987.

387. M. S. Taqqu. Weak convergence to fractional Brownian motion and to the Rosenblatt process. *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete*, 31:287–302, 1975.

388. M. S. Taqqu. Convergence of integrated processes of arbitrary Hermite rank. *Zeitschrift für Wahrscheinlichkeitstheorie und verwandte Gebiete*, 50:53–83, 1979.

389. M. S. Taqqu. A bibliographical guide to self-similar processes and long-range dependence. In E. Eberlein and M. S. Taqqu, editors, *Dependence in Probability and Statistics*, pages 137–162, Boston, 1986. Birkhäuser.

390. M. S. Taqqu. Self-similar processes. In S. Kotz and N. Johnson, editors, *Encyclopedia of Statistical Sciences*, pages 352–357. Wiley, New York, 1988. Volume 8.

391. M. S. Taqqu and J. Levy. Using renewal processes to generate long-range

dependence and high variability. In E. Eberlein and M. S. Taqqu, editors, *Dependence in Probability and Statistics*, pages 73–89, Boston, 1986. Birkhäuser.

392. M. S. Taqqu and V. Teverovsky. Robustness of Whittle-type estimates for time series with long-range dependence. Preprint, 1995.
393. M. S. Taqqu and V. Teverovsky. Semi-parametric graphical estimation techniques for long-memory data. In *Proceedings of the Athens Conference on Applied Probability and Time Series Analysis*, New York, 1996. Springer-Verlag. Time series volume in honour of E. J. Hannan. To appear.
394. M. S. Taqqu, V. Teverovsky, and W. Willinger. Estimators for long-range dependence: an empirical study. *Fractals*, 3(4):785–798, 1995.
395. N. Terrin and M. S. Taqqu. A noncentral limit theorem for quadratic forms of Gaussian stationary sequences. *Journal of Theoretical Probability*, 3:449–475, 1990.
396. N. Terrin and M. S. Taqqu. Convergence in distribution of sums of bivariate Appell polynomials with long-range dependence. *Probability Theory and Related Fields*, 90:57–81, 1991.
397. N. Terrin and M. S. Taqqu. Convergence to a gaussian limit as the normalization exponent tends to 1/2. *Statistics and Probability Letters*, 11:419–427, 1991.
398. N. Terrin and M. S. Taqqu. Power counting theorem on R^n. In R. Durrett and H. Kesten, editors, *Spitzer Festschrift*, pages 425–440. Birkhäuser, Boston, 1991.
399. V. Teverovsky and M. S. Taqqu. Testing for long-range dependence in the presence of shifting means or a slowly declining trend using a variance-type estimator. Preprint, 1995.
400. D. N. C. Tse, R. G. Gallager, and J. N. Tsitsiklis. Statistical multiplexing of multiple time-scale Markov streams. *IEEE Journal on Selected Areas in Communications*, 13:1028–1038, 1995.
401. D. Veitch. Novel methods of broadband traffic. In *Proceedings of Globecom '93*, pages 1057–1061, Houston, TX, 1993.
402. W. Vervaat. Properties of general self-similar processes. *Bulletin of the International Statistical Institute*, 52(Book 4):199–216, 1987.
403. M. C. Viano, Cl. Deniau, and G. Oppenheim. Long-range dependence and mixing for discrete time fractional processes. *Journal of Time Series Analysis*, 16:323–338, 1995.
404. R. F. Voss. Fractals in nature: from characterization to simulation. In H.-O. Peitgen and D. Saupe, editors, *The Science of Fractal Images*, chapter 1, pages 21–70. Springer-Verlag, New York, 1988.
405. A. Weiss. An introduction to large deviations for communication networks. *IEEE Journal on Selected Areas in Communications*, 13:938–952, 1995.

406. W. Whitt. Tail probabilities with statistical multiplexing and effective bandwidths in multiclass queues. *Telecommunication Systems*, 2:71–107, 1993.

407. P. Whittle. *Hypothesis Testing in Time Series Analysis*. Hafner, New York, 1951.

408. E. Willekens and J. L. Teugels. Asymptotic expansion for waiting time probabilities in an M/G/1 queue with long-tailed service time. *Queueing Systems*, 10:295–312, 1992.

409. W. Willinger. Traffic modeling for high-speed networks: theory versus practice. In F. P. Kelly and R. J. Williams, editors, *Stochastic Networks*, volume 71, pages 395–409. Springer Verlag, 1995. IMA Volume in Mathematics and its Applications.

410. W. Willinger, M. S. Taqqu, W. E. Leland, and V. Wilson. Self-similarity in high-speed packet traffic: analysis and modeling of Ethernet traffic measurements. *Statistical Science*, 10:67–85, 1995.

411. W. Willinger, M. S. Taqqu, R. Sherman, and D. V. Wilson. Self-similarity through high-variability: statistical analysis of Ethernet LAN traffic at the source level. *Computer Communications Review*, 25:100–113, 1995. Proceedings of the ACM/SIGCOMM'95, Boston, August 1995.

412. W. Willinger, M. S. Taqqu, R. Sherman, and D. V. Wilson. Self-similarity through high-variability: statistical analysis of Ethernet LAN traffic at the source level (Extended Version). Preprint. The paper also contains the mathematical proof that the superposition of strictly alternating ON/OFF sources converges to fractional Brownian motion, 1995.

413. W. Willinger, D. V. Wilson, W. E. Leland, and M. S. Taqqu. On traffic measurements that defy traffic models (and vice versa): self-similar traffic modeling for high-speed networks. *ConneXions*, 8(11):14–24, 1994.

414. G. W. Wornell. Wavelet-based representations for the $1/f$ family of fractal processes. *Procceedings of the IEEE*, 81:1428–1450, 1992.

415. G. W. Wornell and A. V. Oppenheim. Estimation of fractal signals from noisy measurements using wavelets. *IEEE Transactions on Information Theory*, 40(3):611–623, 1992.

416. G. W. Wornell and A. V. Oppenheim. Wavelet-based representations for a class of self-similar signals with application to fractal modulation. *IEEE Transacations on Iinformation Theory*, 38(2):785–800, 1992.

417. W. Wyss. Fractional noise. *Foundations of Physics Letters*, 4(3):235–246, 1991.

418. Y. Yajima. On estimation of a regression model with long-memory stationary errors. *The Annals of Statistics*, 16:791–807, 1988.

419. Y. Yajima. Asymptotic properties of LSE in a regression model with long-memory stationary errors. *The Annals of Statistics*, 19:158–177, 1991.

420. V. M. Zolotarev. *Odnomernye ustoichivye raspredeleniya*. Nauka, Moscow,

1983. Subsequently translated as "One-dimensional Stable Distributions", American Mathematical Society, 1986.