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Modeling of Statistically Multiplexed Non Uniform Activity VBR Video

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***Abstract*—**This paper reports the feasibility of the ARMA model to describe a bursty video source transmitting over a AAL5 ATM link (VBR traffic). The traffic represents the activity of the action movie "Lethal Weapon 3" transmitted over the ATM network using the Fore System AVA-200 ATM video codec with a peak rate of 100 Mbps and a frame rate of 25. The model parameters were estimated for a single video source and independently multiplexed video sources. It was found that the model ARMA (2, 4) is well-suited for the real data in terms of average rate traffic profile, probability density function, autocorrelation function, burstiness measure, and the pole-zero distribution of the filter model.

***Keywords*—**ARMA, ATM networks, burstiness, multimedia traffic, VBR video.

I. Introduction

MULTIMEDIA applications, such as video phone, video teleconferencing, and video-on-demand, constitute the major sources of Broadband Integrated Services Digital Networks (B-ISDN) traffic. Modeling variable bit rate (VBR) video traffic is a very important area of video research in ATM networks [1] –[5] because it is the core of video traffic control.

Using MPEG coding, the size of video frames significantly varies as the sequence is being generated, yielding VBR traffic. The technology selected to deliver the B-ISDN services is the asynchronous transfer mode (ATM), mainly because ATM employs statistical multiplexing which allows the network to take advantage of the bit rate fluctuation of individual sources.

Stochastic video traffic models are needed for evaluating the performance of B-ISDN traffic over ATM networks, either by means of theoretical analysis or simulation. The knowledge of traffic characteristics plays one of the most important roles in network design since accurate characterization of traffic streams is essential to dimensioning and allocating network resources and provisioning acceptable level of quality of service (QoS). This research will concentrate on modelling the frame sizes of MPEG-encoded video sequences and the stochastic characteristics of VBR video when frame sequences are transmitted through an ATM network.

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The actual measurement is made by ESPRIT LTR 20.113 Measure Project, University of Cambridge Computer Laboratory. Details of their work and analysis can be found at the URL: www.cl.cam.ac.uk/Research/SRG/bluebook.html. The measurement which this report is based on can be found in the ftp host ftp.cl.cam.ac.uk (login: anonymous; directory: fairdata/ava-trace/lethal-weapon-3; files: lw3.63.25.gz. The cell time is 3.55555556 microseconds).

II. Analysis of a Real Single VBR Video Source

A. Data File Processing

The first entry of the data file is the number of sample recorded in the file. The subsequent entries logged the inter-cell time for each cell, including the cell itself. The unit of measurement is ~3.56 μs. Apparently, there are periodic spurious entries in the file that are larger than 6000 (some careful thought about this spurious behaviour suggested that it is caused by the idle time, or the bottleneck, introduced by the frame rate of 25. The long inter-cell time may have been due to the idle time after all information has been transferred within 1 frame), a Perl script "filter" is used to eliminate these errors. The arrival rate is calculated based on the number of cells arrived in 100 unit time, i.e. 356 μs. This again is done by a Perl script "aggregate". However, the initial analysis used an aggregate time of 3.56 ms, resulting in an inferior ARMA modeling. The analysis of such case can be found in section 4.2 entitled "Analysis with a Longer Aggregate Time".

B. Analysis of a Single Sequence with Real Data

In this paper, we study the traffic arrival rate of the coded video sequences displayed in Table I. In order to obtain meaningful autocorrelation sequence and to simplify the system modelling in the latter section, the actual arrival rate data is subtracted from its mean so that it will become a time series of zero mean. The offset arrival rate, its probability distribution (pdf) and the normalised autocorrelation (the offset autocorrelation is by definition the same as the autocovariance and it is normalised by the value at lag 0) are illustrated in Fig. 1, Fig. 2, and Fig. 3, respectively.

The statistical characteristics of the sequence s_1 is given in Table II.

III. ARMA Parameters Estimation

Fig. 4 depicts the generic structure of the ARMA model from which the AR and MA (moving average) models degenerate. In the Z-domain, the model is described by

TABLE I
VALUES OF THE TRAFFIC SEQUENCE $\{s_i\}$

Seq	Data Points
s_1	1-1000
s_2	5001-6000
s_3	10001-11000
s_4	15001-16000
s_5	20001-21000
s_6	25001-26000
s_7	30001-31000
s_8	35001-36000
s_9	40001-41000
s_{10}	45001-46000

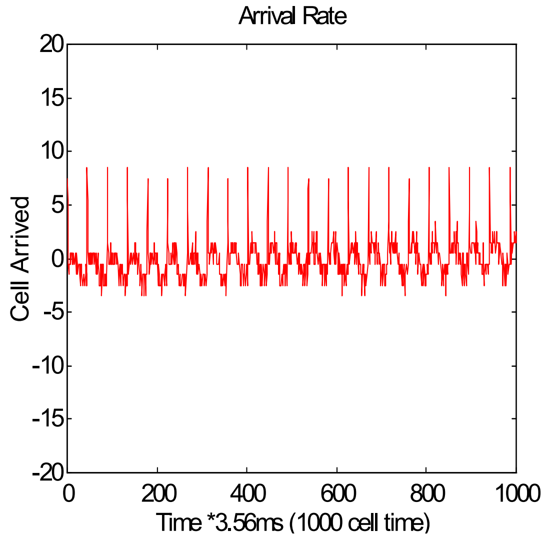

Fig. 1 The offset video arrival rate of real data s_1

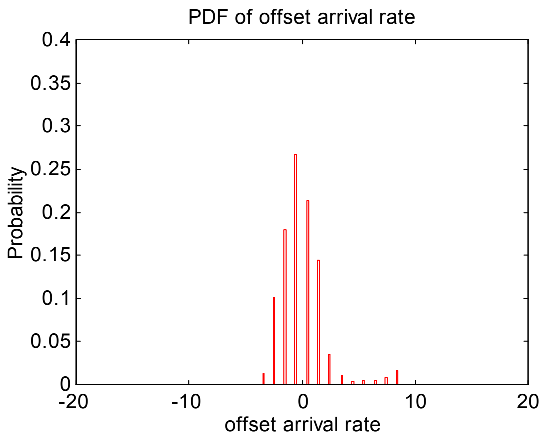

Fig. 2 The pdf of the real arrival rate for data s_1

$$G(z)=\frac{B(z)}{A(z)},H(z)=\frac{C(z)}{A(z)}$$
$$A(z)=1+\sum_{k=1}^{na}a_k z^{-k},B(z)=\sum_{k=1}^{nb}c_k z^{-k} \quad (1)$$
$$C(z)=1+\sum_{k=1}^{nc}c_k z^{-k},Y=GU+HE$$

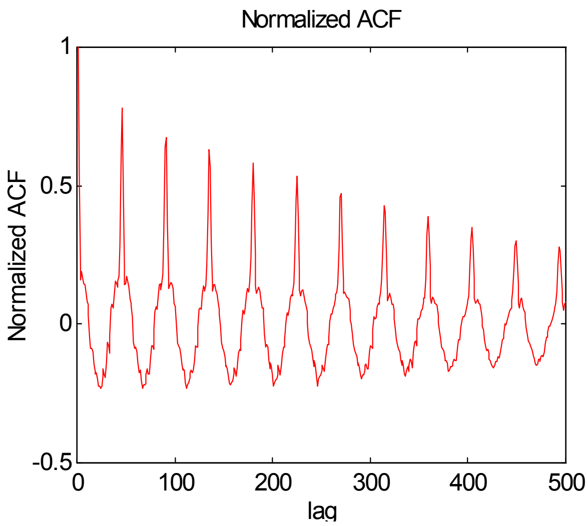

Fig. 3 The normalized autocorrelation of the real data s_1

TABLE II
STATISTICS OF THE TRAFFIC SEQUENCE s_1

mean	7.5150
var	4.0078
burstiness	2.1291

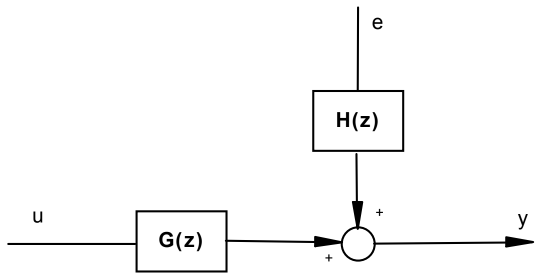

Fig. 4 General structure of the ARMA

where *na*, *nb*, and *nc* are the model order and *u* is refered to as the control signal. There are several special cases: AR(*na*), Auto Regressive, *nb* = *nc* = 0; MA(*nc*), Moving Average, *na* = *nb* = 0; ARMA(*na*, *nc*), Auto Regressive Moving Average, *nb* = 0 (the control signal is not used).

The model order is determined empirically by an MA model of very high order (*na* = 20), then the order is gradually decreased until the output from the model filter resembles that of the time series. The AR part order is then increased to fine tune the estimate so that the autocorrelation resembles that of the data. "Over-modelling" is avoided by observing the degree of improvement when increasing the filter order. The parameters are estimated by using Matlab System Identification Toolbox. It is found that and ARMA(2, 4) model is sufficient to preserve the statistical characteristics of the data (The e signal is a zero-mean white Gaussian noise of unit variance). The simulated traffic rate profile and its ACF are illustrated in Figs. 5 and 6. The estimated model parameters are tabulated in Table III.

IV. Statistical Multiplexing of Video Sources

In this section, the sources are multiplexed by adding their arrival rates. We denote by M_k the arrival rate resulting from multiplexing data s_1 to s_k. The burstiness (B = peak/mean) results are summarised in Table IV and Figs. 7 and 8. The estimated model parameters are shown in Table V.

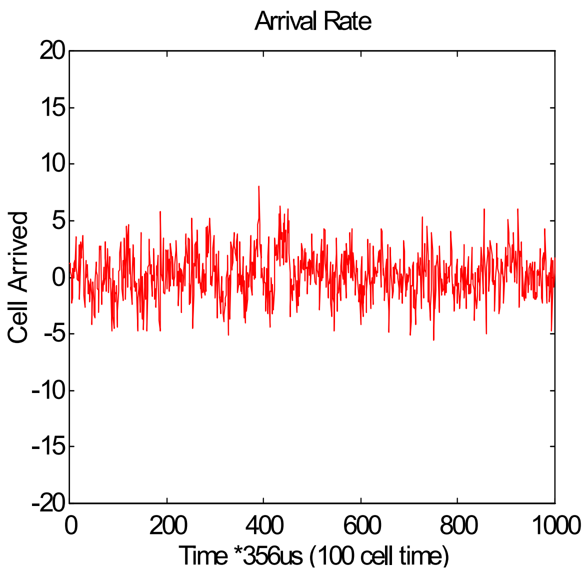

Fig. 5 Simulated modeled s_1 offset arrival rate

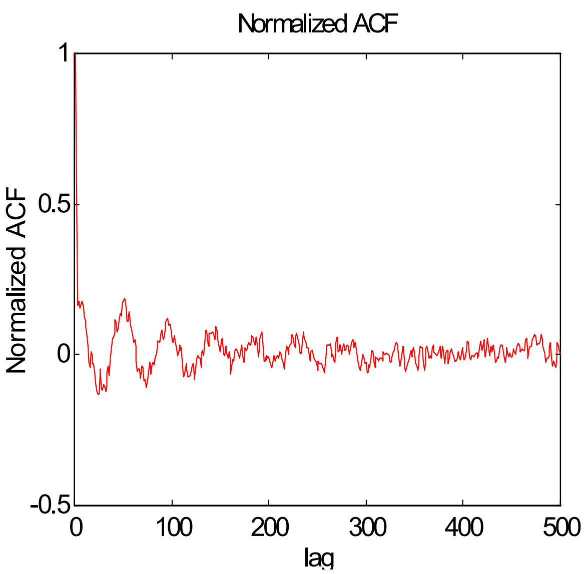

Fig. 6 Simulated modeled s_1 normalised ACF

TABLE III
SIMULATED s_1 FILTER COEFFICIENTS AND STATISTICS

Order	A	C
0	1	1
1	-1.9635	-1.49
2	0.9836	0.1332
3		0.3472
4		0.0574
var(in)	3.087	
burstiness	1.677	

TABLE IV
COMPARISON OF SIMULATED RESULTS FOR THE MULTIPLEXED SOURCES

		Real		Simulated	
Multiplex level	mean	var	burstiness	var	burstiness
1	7.515	4.0078	2.1291	3.087	1.6770
2	15.128	7.7376	1.7187	8.3271	1.5680
3	22.659	9.7807	1.5005	9.9534	1.6286
4	29.847	12.2796	1.4072	12.8088	1.1068
5	36.905	13.764	1.3819	15.2733	1.3794
6	44.982	18.2177	1.3561	18.4343	1.2789
7	52.492	23.2739	1.3335	23.1551	1.6491
8	59.691	28.5275	1.3067	29.9307	1.4009
9	67.443	31.3788	1.2752	31.3446	1.0638
10	75.57	33.5711	1.2571	32.0827	1.1392

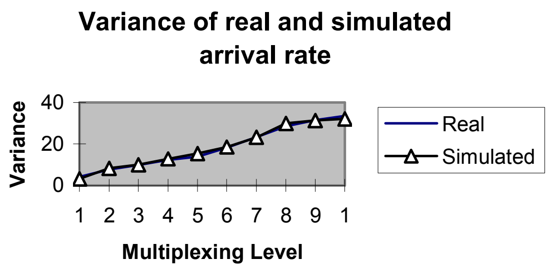

Fig. 7 Variance versus multiplexing level

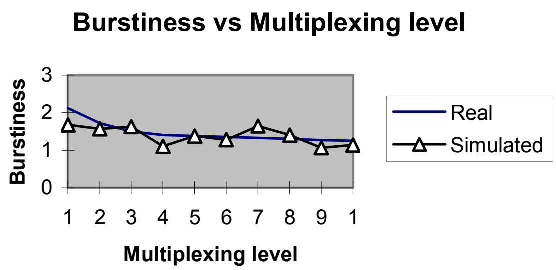

Fig. 8 Burstiness versus multiplexing level

A. Graphical Summary

Simulation results for different multiplexing levels M are illustrated in Figs. 9 to 11. In each Figure, the graphs are sub-divided as follows: (a) Real source arrival rate; (b) Model-based simulated arrival rate; (c) Autocorrelation of the real sources; (d) ACF of model-based simulated source; (e) pdf of thereal source offset arrival rate; (f) Pole-zero diagram of the ARMA model $H(z)$ ('x' for AR, 'o' for MA).

B. Analysis with a Longer Aggregate Time

In this section we use used a longer aggregate time of 3.56 ms (previously, we used 0.356 ms) for which the mean μ = 69.8672 cell/aggregate time, B = peak/mean = 1.8893, and σ^2 = 97.2838. In order to obtain meaningful autocorrelation sequence and to simplify the system modeling, the actual arrival rate data is subtracted from its mean to yield a time series of zero mean. The probability density function of the arrival rate of the real data is given in Fig. 12(a). For the model ARMA(8, 6), the estimated coefficients of $A(z)$ and $C(z)$ are given in Table VI, and the corresponding diagram of the transfer function (Z-domain) $H(z) = C(z)/A(z)$ is given in Fig. 12(b).

TABLE VI
COEFFICIENTS $A(z)$ AND $C(z)$ FOR ARMA(8,6)

order	*A*	*C*
1	1.5142	1.47
2	0.923	0.8539
3	-0.0239	-0.0487
4	-0.0998	-0.0267
5	-1.0804	-0.0514
6	-1.4625	-0.0179
7	-0.7923	
8	0.0901	

V. CONCLUSION

In this paper, we investigated the feasibility of the ARMA model to describe non-uniform activity level (multi-scene) bursty VBR video sources. We particularly selected a video source whose traffic represents the activity of the action movie "Lethal Weapon 3" transmitted over a AAL5 ATM link. ATM network using the Fore System AVA-200 ATM video codec with a peak rate of 100 Mbps and a frame rate of 25. The model parameters were estimated for a single video source and independently multiplexed video sources. It was found that the model ARMA (2, 4) is well-suited for the real data in terms of the average rate traffic profile, the probability density function, and autocorrelation function. The model was also consistent with the smoothing effect or burstiness reduction caused by statistical multiplexing.

In addition, the analysis of independently multiplexed sources verified the statistical multiplexing smoothing gain in terms of a wider probability density function (spreading while maintaining unit area), a wider autocorrelation function, a lower burstiness factor (measure by the peak-to-mean ratio), and in terms of the distribution of the pole-zero diagram of the filter model.

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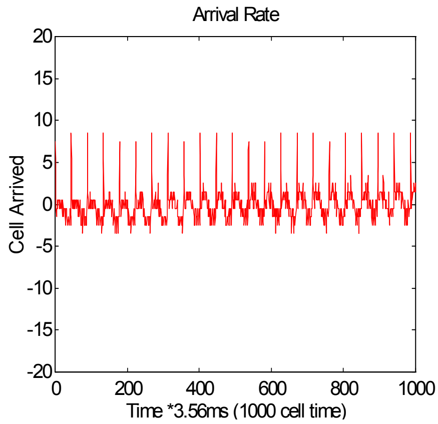


Fig. 9(a)

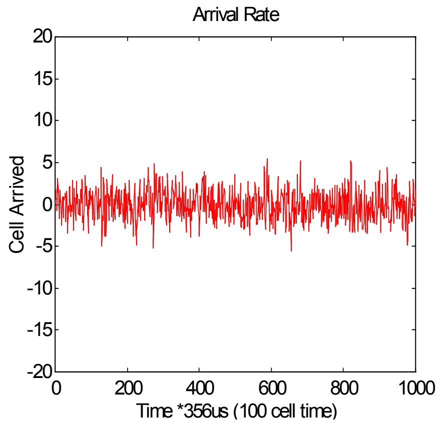


Fig. 9(b)

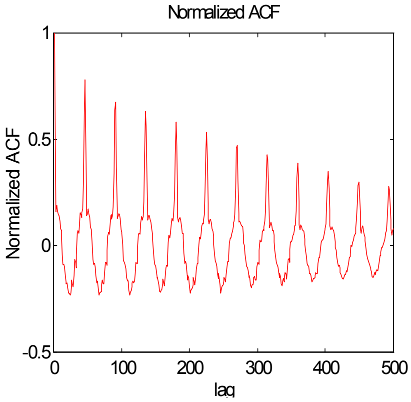


Fig. 9(c)

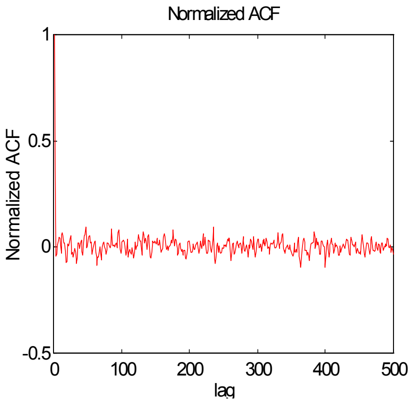


Fig. 9(d)

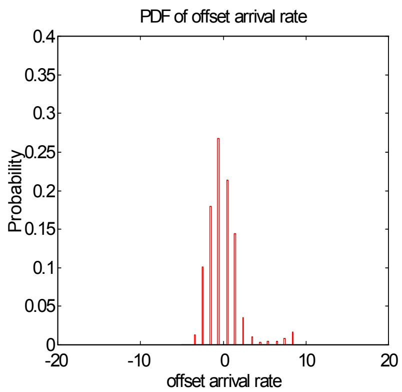


Fig. 9(e)

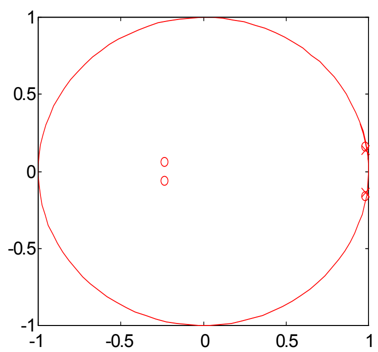


Fig. 9(f)

Fig. 9 Graphical summary for $M = 1$ (single source)

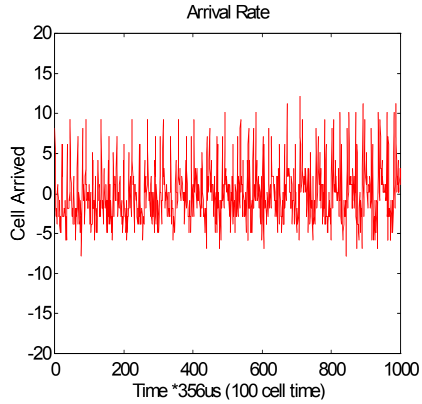


Fig. 10(a)

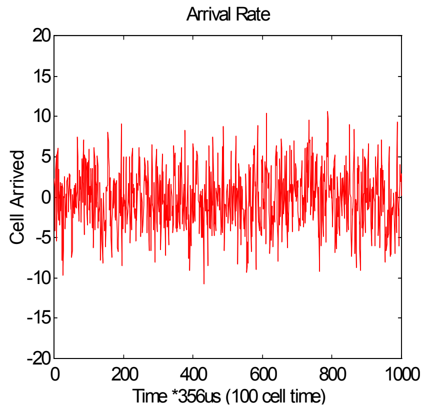


Fig. 10(b)

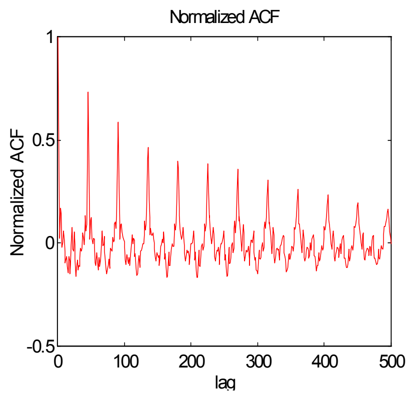


Fig. 10(c)

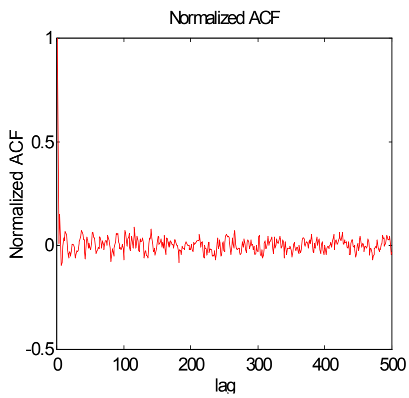


Fig. 10(d)

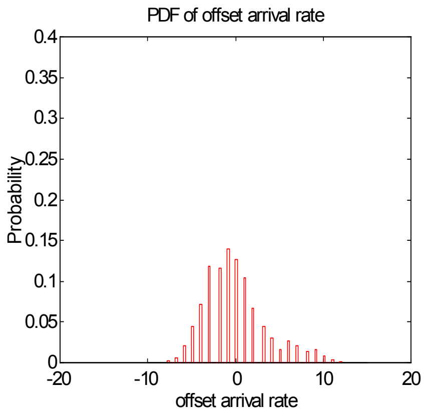


Fig. 10(e)

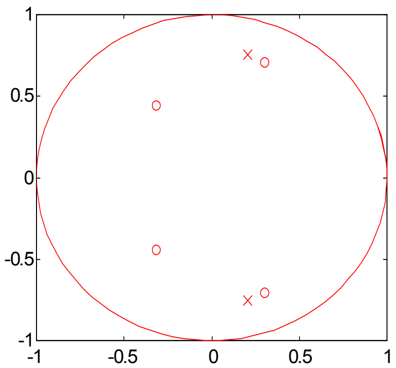


Fig. 10(f)

Fig. 10 $M = 4$ (four independently multiplexed sources)

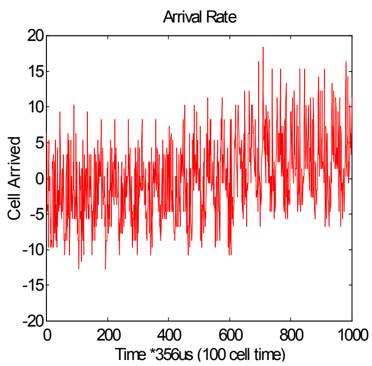


Fig. 11(a)

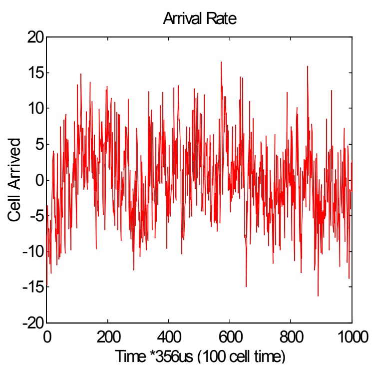


Fig. 11(b)

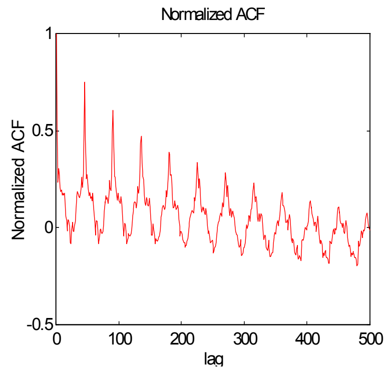


Fig. 11(c)

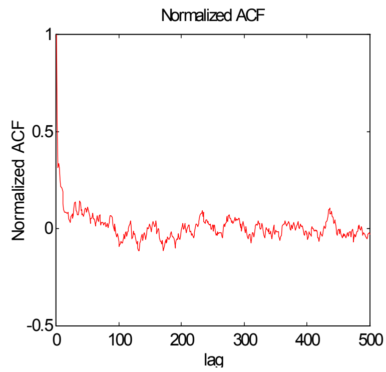


Fig. 11(d)

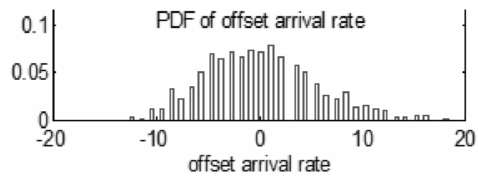


Fig. 11(e)

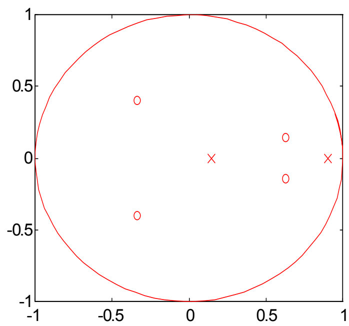
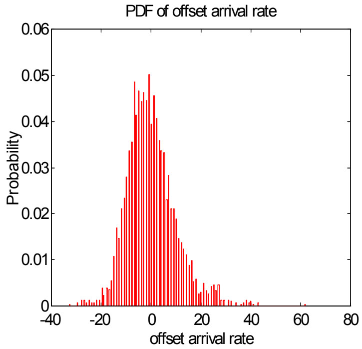
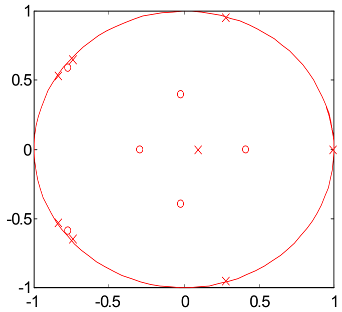


Fig. 11(f)

Fig. 11 $M = 8$ (eight independently multiplexed sources)



(a) PDF of the real data



(b) Pole-zero diagram of $H(z)$: 'x' for AR, 'o' for MA

Fig. 12 ARMA(8,6) for single source with longer aggregate time (3.56ms)

TABLE V
ESTIMATED ARMA MODEL COEFFICIENTS

Mux level	1	2	3	4	5	6	7	8	9	10
AR/a_0	1	1	1	1	1	1	1	1	1	1
a_1	-1.9635	-1.6865	-0.2263	-0.4072	-0.0805	-0.9743	-0.8513	-1.0448	-0.7919	-0.1108
a_2	0.9836	0.7224	0.753	0.6088	0.828	0.228	0.0423	0.1291	-0.2053	-0.7984
MA/c_0	1	1	1	1	1	1	1	1	1	1
c_1	-1.4974	-1.1833	0.2993	0.0268	0.3132	-0.5058	-0.3924	-0.5895	-0.2856	0.4181
c_2	0.1332	0.0085	0.7064	0.5096	0.838	-0.0837	-0.1342	-0.1559	-0.4335	-0.6641
c_3	0.3472	0.2174	0.3403	0.1945	0.2544	0.019	-0.0684	-0.0666	-0.2409	-0.4176
c_4	0.0574	0.0891	0.1356	0.1759	0.0914	0.1235	0.0971	0.1158	-0.0109	-0.1376