A Source Model for File Transfer Applications in Local ATM Networks *

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Abstract

This paper aims at the study of the file transfer application traffic in IP over ATM environment. Based on empirical data collected during file transfers a source model for IP datagrams arriving at the network interface cards is proposed.

1 Introduction

ATM has become a competitive technology in local and wide area data networking, therefore it has to support transparently the applications based on legacy network technologies (IP, Token Ring, FDDI, ...). In order to solve this different approaches were proposed: LAN Emulation, Multiprotocol over ATM, IP over ATM. Due to the explosion of Internet, the IP over ATM solution will play a significant role in interworking between ATM and Internet. Hence, a clear understanding of the traffic behaviour of applications in an IP over ATM environment is needed.

There are many Internet applications whose behaviour can be of interest, but our focus in this paper is the study of the characteristics of a file transfer application (ftp), since file transfers contribute a significant part to the Internet traffic. Moreover, our attention is to characterize the arrival process of IP datagrams of a file transfer at the ATM Adaptation Layer (AAL) in the IP over ATM environment. Since the characteristics of a file transfer application may depend on the physical layer of the network, the behaviour of the IP datagram arrival process in Ethernet is also studied in this paper.

Based on the statistical analysis a source model for IP datagrams arriving at the ATM Adaptation Layer is proposed. The interarrival times of IP datagrams are modelled with a phase-type process where the phase-type distribution is modified by a deterministic "vacation" time.

The rest of the paper is organised as follows. In the next section the statistical analysis of the data traces is presented. Section 3 describes the proposed source model. Finally the paper is concluded.

2 Statistical analysis of data traces

The experiments to collect data traces were carried out in a local ATM configuration which comprises one ForeRunner ASX200BX switch from Fore Systems Inc., two Pentiums running

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Linux equipped with 155 Mbit/s ATM Network Interface Cards (NIC). The NICs are from Fore Systems and Efficent Networks. The local ATM environment is configured as TCP/IP over ATM, however the workstations are connected to Ethernet as well. The MTU of the Ethernet and ATM interface is configured to be of 1500 and 9180 bytes, respectively. For all traffic measurements, the packet trace collection tool was a modified version of tcpdump [?].

In the experiments the transfers of files of size 1, 2, 5 and 10 Mbytes were performed with the Unix `ftp` program, respectively. For the purpose of the statistical analysis three data sets were used: the first one is a packet trace of a 5-Mbyte file transfer, the second one is a packet trace of 10-Mbyte file transfer and the third one is an aggregated of all data traces.

The `ftp` program first opens a command TCP connection for exchanging commands (e.g. initiated by an user interface) between the ftp client and server. If there is a file to be sent a new TCP data connection is opened. Since in each experiment only one file is transfered and the interaction with the user interface is minimal (Table 1), only the behaviour of the ATM connection is mainly influenced by the IP datagrams sent over the data connection. Therefore only the statistics concerning the data connection are taken into account in the statistical analysis.

Ethernet						
Data set	**Data connection**		**Command connection**		**Both connections**	
	Number of messages	Average msg length	Number of messages	Average msg length	Number of messages	Average msg length
5Mb file transfer	3708	1422.8	23	44.1	3731	1414.3
10Mb file transfer	7469	1420.5	22	44.4	7491	1416.5
accumulated data	7469	1420.5	89	44.3	13303	1417.9
ATM						
Data set	**Data connection**		**Command connection**		**Both connections**	
	Number of messages	Average msg length	Number of messages	Average msg length	Number of messages	Average msg length
5Mb file transfer	581	185.2	22	2.09	603	178.5
10Mb file transfer	1208	178.2	22	2.09	1230	175.1
accumulated data	2140	181.0	92	2.09	2232	173.7

Table 1: Number of the IP datagrams in the command and the data connections during FTP sessions

In the TCP/IP environment, the application data is broken into segments whose size is governed by the Maximum Transfer Unit (MTU) and the current window size of the TCP protocol. The measurement is carried out in a local environment with very small round-trip time, therefore the current window values of TCP in the file application are almost above the MTU. As a consequence most IP datagrams transfered in ATM have a size of maximum transfer unit (1500 bytes on Ethernet, 192 cells in the IP over ATM) and 2% of datagrams are shorter than 80 cells, which is illustrated in Figure 1.

In Table 2, Figure 2 and Figure 3 the statistics of datagrams interarrival times are plotted. It is observed that there is no significant correlation between the interarrival times of the datagrams. Moreover, the threshold for the interarrival time exists in all traces (about 160μsec in Ethernet, 220μsec in ATM). Note that the value of the minimum interval between the arrival instants of two consecutive datagrams depends on the processing time of datagrams.

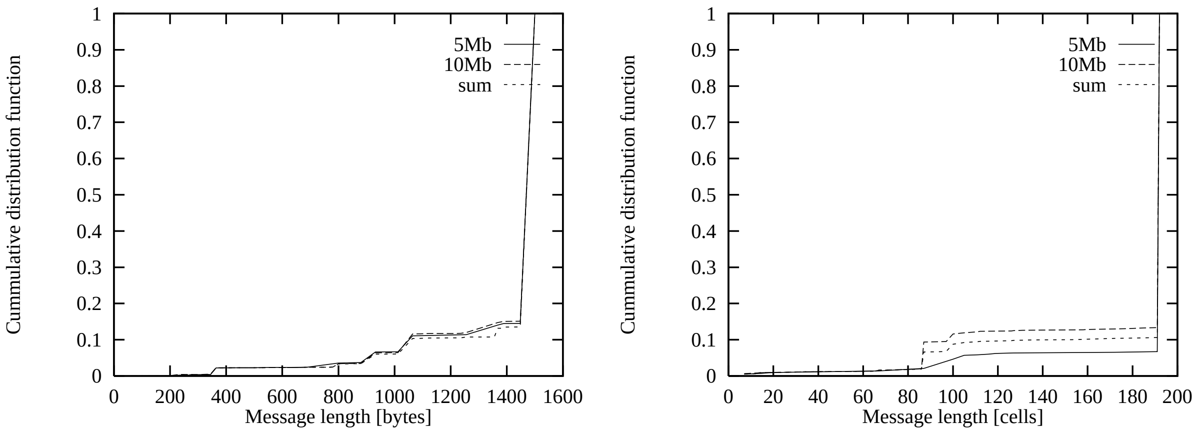

Figure 1: Cumulative distribution function of IP datagram length in the data connection, Ethernet on the lhs, ATM on the rhs

Ethernet					
Data set	Number of messages	Intararrival time			
		Mean	CoV	5percentile	95percentile
5Mb file transfer	3708	3876.0	106.4	1593	12646
10Mb file transfer	7469	4042.3	159.8	1569	12775
accumulated data	13214	3834.3	211.8	1563	12086
ATM					
Data set	Number of messages	Intararrival time			
		Mean	CoV	5percentile	95percentile
5Mb file transfer	581	5632.6	49.78	264	15031
10Mb file transfer	1208	7180.6	103.8	266	23778
accumulated data	2140	6373.9	126.1	263	18009

Table 2: The characteristics of the interarrival time distribution

3 A source model

Based on the statistical analysis conducted, a following source model for file transfers in local networks is proposed:

1. For data connections datagrams arrive with the maximum size. This approximation covers the worst case scenario of the arrival process for further mathematical analysis which will be reported in the future version of this paper.

2. There is a minimum of interarrival time (about 220μsec in ATM, 160μsec in Ethernet). As a consequence, the interarrival times are idependent indentically distributed random variables and are modelled with a renewal process in which the interarrival time is a phase-type distribution modified by a deterministic "vacation" time after each arrival. An example of the model with a two-state phase-type distribution and the deterministic delay time is shown in Figure 4. Messages arrives when the system enters state 2 and the system step in state 0 (the initial state of the phase-type process) after the deterministic

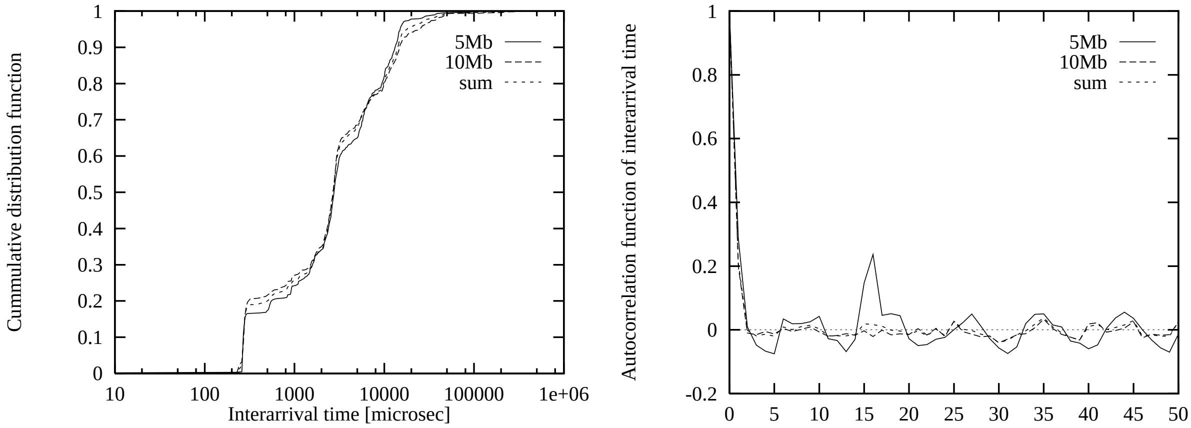

Figure 2: Cumulative distribution and autocorrelation function of message interarrival time in the data connection, ATM

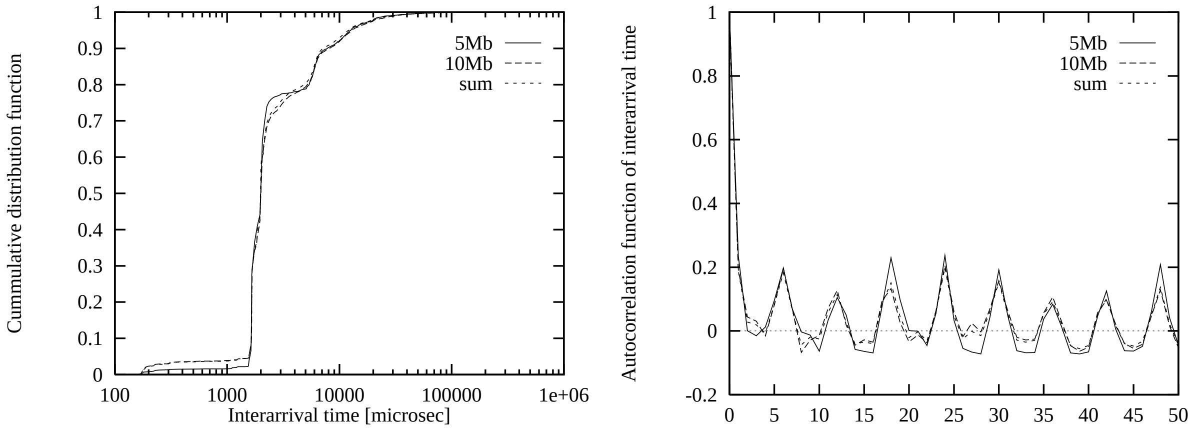

Figure 3: Cumulative distribution and autocorrelation function of message interarrival time in the data connection, Ethernet

waiting time (T_{min}). We chose this combination of a phase-type model with a deterministic waiting time after each arrival since the phase-type distribution does not properly model the minimum interarrival time.

The phase-type distribution is characterized by the initial distribution vector (b) and the generator matrix (Q).

In order to decrease the number of parameters of the phase-type model we consider the canonical representation of Acyclic Phase-Type distributions [**?**] with the following properties:

- The phase-type process starts from state 0 with probability 1 (as in the example of Figure 4):
$$b = [1, 0, \ldots, 0]$$
- From state i only state $(i+1)$ and the last state (state 2 in Figure 4), which represents the new arrival, is reachable directly. Hence structure of the Q matrix with an N-state phase-type process is the following:
$$Q = \left[\begin{array}{ccccc|c} q_{00} & q_{01} & 0 & 0 & \cdots & q_{0N} \\ 0 & q_{11} & q_{12} & 0 & \cdots & q_{1N} \\ \vdots & & \ddots & \ddots & & \vdots \end{array} \right]$$

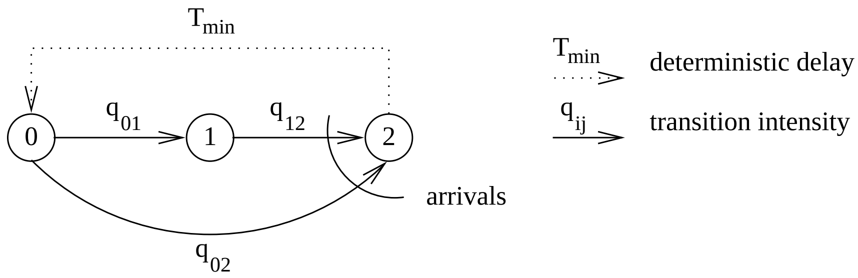

Figure 4: The arrival process model with a two-state phase-type distribution and the deterministic delay

We used the method described in [?] to get the parameters of the phase-type distribution with different number of states in Figure 5 and 6.

The goodness of the parameter matching is demonstrated in Figure 7 and 8.

$$Q_2 = \left[\begin{array}{cc|c} -9.36 \cdot 10^{-2} & 9.19 \cdot 10^{-2} & 1.7 \cdot 10^{-3} \\ 0 & -2.69 \cdot 10^{-4} & 2.69 \cdot 10^{-4} \\ 0 & 0 & 0 \end{array}\right]$$

$$Q_4 = \left[\begin{array}{cccc|c} -8.35 \cdot 10^{-2} & 8.35 \cdot 10^{-2} & 0 & 0 & 0 \\ 0 & -2.00 \cdot 10^{-1} & 1.95 \cdot 10^{-1} & 0 & 5 \cdot 10^{-3} \\ 0 & 0 & -1.84 \cdot 10^{-3} & 1.84 \cdot 10^{-3} & 0 \\ 0 & 0 & 0 & -3.12 \cdot 10^{-4} & 3.12 \cdot 10^{-4} \\ 0 & 0 & 0 & 0 & 0 \end{array}\right]$$

Figure 5: The generator matrices of the source model, Ethernet

$$Q_2 = \left[\begin{array}{cc|c} -2.23 \cdot 10^{-2} & 1.81 \cdot 10^{-2} & 4.2 \cdot 10^{-3} \\ 0 & -1.34 \cdot 10^{-4} & 1.34 \cdot 10^{-4} \\ 0 & 0 & 0 \end{array}\right]$$

$$Q_4 = \left[\begin{array}{cccc|c} -7.17 \cdot 10^{-2} & 7.17 \cdot 10^{-2} & 0 & 0 & 0 \\ 0 & -7.17 \cdot 10^{-2} & 7.17 \cdot 10^{-2} & 0 & 0 \\ 0 & 0 & -7.17 \cdot 10^{-2} & 5.84 \cdot 10^{-2} & 1.33 \cdot 10^{-2} \\ 0 & 0 & 0 & -1.34 \cdot 10^{-4} & 1.34 \cdot 10^{-4} \\ 0 & 0 & 0 & 0 & 0 \end{array}\right]$$

Figure 6: The generator matrices of the source model, ATM

Discrete time queuing analysis

3.1 System model

Since we can only measure the throughput of the TCP/IP connections we use a queueing analysis with the above described source model to approximate the message delay in the transmitter buffer.

The source process is a Markov process except in the state where the deterministic delay happens (state 2 in Figure 4). By omitting the time spent in this state we get a continuous time Markov chain (Figure 9) modulating the cell arrival in our source model. To fit this (continuous time) source model to the discrete nature of data transmission over an ATM connection we

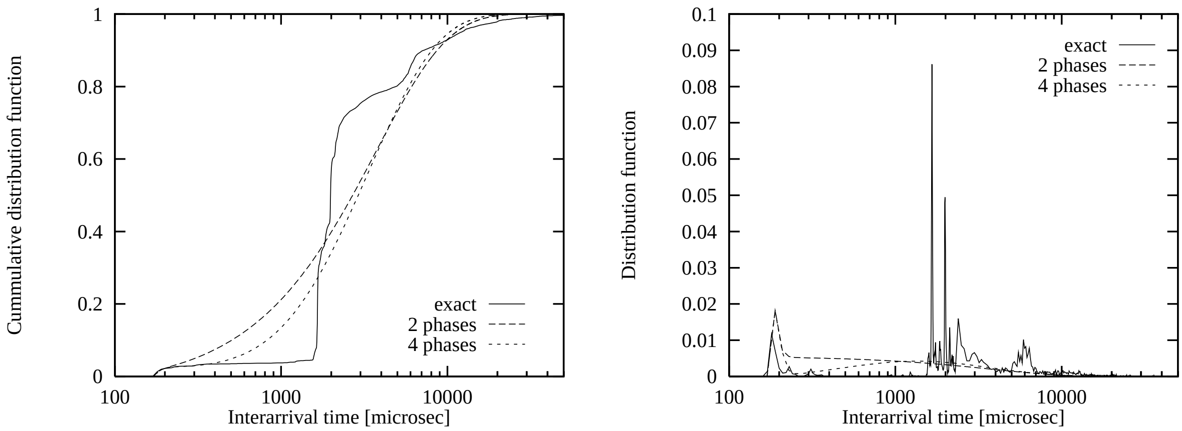

Figure 7: Interarrival time approximation with the source model, Ethernet

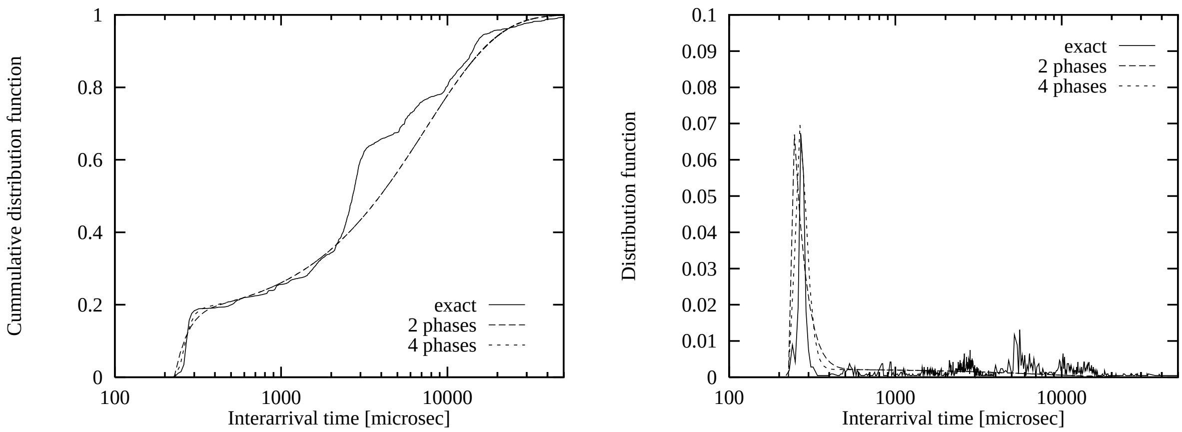

Figure 8: Interarrival time approximation with the source model, ATM

consider message arrivals only at the end of the ATM (cell) time slots. This way we have a discrete time source model feeding a discrete time queueing system.

The approximation that the messages arrives at the end of the time slots does not cause a significant error since the cell time is quite short (2.7 μsec) comparing to the average interarrival time (5-7 msec). The restriction that only one message may arrive during a time slot corresponds to the data traces as the minimum interarrival time (T_{min}) is much greater than the cell time.

We are going to study the stochastic process describes the number of cells in the buffer. The lifetime of this stochastic process is composed by two kinds of intervals (Figure 9). On the one hand, while the source process stays in the deterministic delay state (state 2 in Figure 4) the buffer content process is deterministic. The buffer content decreases by one cell in every ATM time slot. And the buffer never gets empty during this phase, because, with our assumptions, the number of cells arrive to the buffer at an arrival instant is more than the number of cells transmitted during T_{min}. On the other hand, while the source process stays in one of the phase-type states (state 0 or 1 in Figure 4) the buffer content process is a stochastic process, which enjoys Markov property at every ATM time slot.

Hence the applied analysis procedure is composed by the following steps:

- Markovian system analysis on the modified time axis.

- Evaluation of the real system behaviour based on the previous step.

3.2 System analysis on the modified time axis

The system behaviour at the n-th ATM time slot (on the modified time axis) is characterized by

- the state of the source (I_n) and
- number of cells in the transmitter buffer (J_n).

The stochastic process $\{I_n, J_n\}$ is a Discrete Time Markov Chain (DTMC). To reach final system preformance parameters first we analyze this DTMC. From the steady state distribution of this DTMC we can obtain the buffer content distribution at message arrival and the distribution of message delay.

The buffer contents will change during the time slots in the following way:

- If no message arrives during a time slot then a cell leaves the spacer if it is not empty:

$$j \to \max(j-1, 0).$$

- If a message with K cells arrives ($K = 192$ in our problem) in a time slot then first the message (K cells) is put in the buffer if there is enough room for it, then 1 cell leaves the buffer if it was not empty at the beginning of the time slot and during the minimum interarrival time $W = \left\lfloor \frac{T_{min}}{C_t} \right\rfloor$ cells leave the buffer if it does not become empty:

$$j \to \max(\max(j-1, 0) + K \cdot I_{j+K<=L} - W, 0)$$

  where L is the buffer size in cells and $I_{j+k<=L}$ is the indicator that there is enough room for the incoming message.

Since normally the number of lost messages in the transmitter buffer is very low we can assume an infinite buffer size for the transmitter buffer for our approximation. If infinite buffer is modeled then the state transition in the latter case will be the following:

$$j \to \max(j-1, 0) + K - W.$$

The probabilities of the state transitions can be obtained from the parameters of the source model:

$$\begin{array}{rcl} D_0(i,l) := \Pr(I_{n+1} = l,\ \text{no message arrives } | I_n = i) & = & e^{(C_t \cdot Q)}(i,l) \\ D_1(i,l) := \Pr(I_{n+1} = l,\ \text{message arrives } | I_n = i) & = & e^{(C_t \cdot Q)}(i,N) \cdot b(l) \end{array}$$

where Q is the generator matrix and b is the initial distribution of the phase-type distribution, $\bullet(i)$ identify a vector element, $\bullet(i,l)$ identify a matrix element and the source phases are $[0, 1, .., N]$.

3.3 The steady state distribution for infinite buffer

According to the above considerations the transition probability matrix of the DTMC can be obtained. Figure 10 shows the structure of the matrix when the messages consist of 5 cells and minimum waiting time is 1 time slot.

Introducing hypermatrices of size $(K-W-1) \times (K-W-1)$ (where K is the number of cells arrive at an arrival instance and W is the number of cells transmitted during T_{min}) we get a quasi-birth-death process with the following transition probability matrix structure:

$$\Pi = \begin{bmatrix} A_0 & B_0 & & & \\ C & A & B & & \\ & C & A & B & \\ & & \ddots & \ddots & \ddots \end{bmatrix}$$

Let's denote the steady state distribution of the DTMC by $p_{i,j}$ and introduce vector $p_j,\ j = 0, 1, \ldots$ as

$$p_j = [p_{0,j}, \ldots, p_{N-1,j}]$$

and vector $v_j,\ j = 0, 1, \ldots$ as

$$v_j = [p_{j(K-W-1)}, \ldots, p_{(j+1)(K-W-1)-1}]$$

The steady state distribution can be obtained by solving the following system of equations:

$$\begin{aligned}
0 &= v_0(A_0 - I) + v_1 C \\
0 &= v_0 B_0 + v_1(A - I) + v_2 C \\
0 &= v_{j-1} B + v_j(A - I) + v_j C \qquad\qquad j \geq 2
\end{aligned}$$

The solution can be found as $v_{j+1} = v_j R$ for $j \geq 1$, where R is the minimal non-zero solution of the following matrix equation:

$$B + R(A - I) + R^2 C = 0$$

A number of methods were proposed for solving this matrix equation [**?**, **?**, **?**, **?**]. In general cases the complexity of these methods is not better than $O(N^3 \cdot (K - W - 1)^3)$, where $N \cdot (K - W - 1)$ is the size of the A, B and C matrices. Nuets [] uses a very simple iterative algorithm to solve the equation:

0) $R_0 = -B(A - I)^{-1}$;

1) $R_{n+1} = -B(A - 1)^{-1} - R_n^2 C(A - I)^{-1}$

2) IF ($\|R_{n+1} - R_n\| \leq \epsilon$) GOTO 1

In our problem the matrices have special structures:

- In the A matrix the elements of the lower subdiagonal are the same non-zero elements, while all the others are zero:

$$A = \begin{bmatrix} 0 & 0 & 0 & \cdots \\ D_0 & 0 & 0 & \cdots \\ 0 & D_0 & 0 & \cdots \\ \vdots & & \ddots & \end{bmatrix}$$

- B matrix is a diagonal matrix:

$$B = \begin{bmatrix} D_1 & 0 & \cdots \\ 0 & D_1 & \\ \vdots & & \ddots \end{bmatrix}$$

- In the C matrix only the upper-right corner element is non-zero:

$$C = \begin{bmatrix} \cdots & 0 & D_0 \\ \cdots & 0 & 0 \\ & \vdots & \vdots \end{bmatrix}$$

Utilizing the special structure of the matrices the complexity of the iteration decrease to $O\left(N^3(K-W-1)^2\right)$ from $O\left(N^3(K-W-1)^3\right)$. In our case $N < 10$ and $K-W-1 \approx 110$, hence the improvement is significant.

The first term of an iteration step is

$$B(A-I)^{-1} = \begin{bmatrix} -D_1 & 0 & 0 & \cdots \\ -D_1 D_0 & -D_1 & 0 & \cdots \\ -D_1 D_0^2 & -D_1 D_0 & -D_1 & \\ \vdots & \ddots & \ddots & \ddots \end{bmatrix}$$

and the second term of the iteration step is

$$R_n C(A-I)^{-1} = R_n \begin{bmatrix} \cdots & -D_0^2 & -D_0 \\ \cdots & 0 & 0 \\ & \vdots & \vdots \end{bmatrix}$$

Since only the first row of the $C(A-I)^{-1}$ contains non-zero elements we only have to calculate the first column of R_n^2:

$$r_n = \begin{bmatrix} \sum_k R_n^{(1k)} \cdot R_n^{(k1)} \\ \sum_k R_n^{(2k)} \cdot R_n^{(k1)} \\ \vdots \end{bmatrix},$$

where $R_n^{(ij)}$ are the $(N+1) \times (N+1)$ submatrices of R_n.

The algorithm with these special matrices reduces to the following steps:

0) $R_0 = -B(A-I)^{-1} = \begin{bmatrix} -D_1 & 0 & \cdots \\ -D_1 D_0 & -D_1 & \\ \vdots & \ddots & \ddots \end{bmatrix}$

1) $R_{n+1} = -B(A-1)^{-1} - R_n^2 C(A-I)^{-1} =$
$\begin{bmatrix} -D_1 & 0 & \cdots \\ -D_1 D_0 & -D_1 & \\ \vdots & \ddots & \ddots \end{bmatrix} + \begin{bmatrix} \sum_k R_n^{(1k)} \cdot R_n^{(k1)} \\ \sum_k R_n^{(2k)} \cdot R_n^{(k1)} \\ \vdots \end{bmatrix} \begin{bmatrix} \cdots & -D_0^2 & -D_0 \end{bmatrix}$

2) IF ($\|R_{n+1} - R_n\| \leq \epsilon$) GOTO 1

3.4 Message delay on the real time axis

By the steady state distribution of the studied DTMC the probability of a message arrival in the system states is:

$$\Pr(J_n = j, I_n = i, \text{message arrives}) = \Pr(J_n = j, I_n = i) \cdot \Pr(\text{message arrives} \mid I_n = i, J_n = j)$$

The message delay in the transmitter buffer is the delay of the last cell of the message. So the delay of a message arriving at the end of a time slot when j cells were in the buffer at the beginning of the time slot is:

$$md(j) = (\max(j-1, 0) + K)C_t$$

The average message delay is the average delay of the last cell of an arriving message:

$$MMDT = \sum_{i=0}^{N} \frac{Pa_i}{Pa} \sum_{j=0}^{\infty} p_{i,j} md(j)$$

where p_{ij} is the steady state distribution of the DTMC, $Pa_i = \sum_{l=0}^{N} D_1(i,l)$ is the probability that a message arrives and the source is in state i and $Pa = \sum_{i=0}^{N} Pa_i$ is the probability that a message arrives.

4 Conclusions

This paper studies the file transfer application traffic in IP over ATM environment in local ATM networks. Measurments show that during file transfers the IP messages have the following main properties:

- Most of the IP messages are close to the MTU during the data transfer.
- There is a minimum interarrrival time between the consecutive IP messages.
- The process of the interarrival times does not show a strong autocorrelation.

Based on the collected data a source model for IP datagrams arriving at the ATM Adaptation Layer is proposed. The interarrival times of IP datagrams are modelled with a phase-type process where the phase-type distribution is modified by a deterministic "vacation" time.

A discrete time queueing analysis of the transmitter buffer with the input process modelled as the proposed source model is also presented. The presented method is the adaptation of the matrix geometric method for our problem.

5 Conclusions

This paper studies the file transfer application traffic in local Ethernet and ATM networks.

Based on the statistical analysis a source model for the arrival process of IP datagrams at the adapters is proposed. The interarrival times of IP datagrams are modelled with a phase-type process where the phase-type distribution is modified by a deterministic "vacation" time.

Figure 9: The modified time axes

$$
\Pi = \begin{bmatrix}
D_0 & 0 & 0 & 0 & D_1 & & & & & \\
D_0 & 0 & 0 & 0 & D_1 & & & & & \\
 & D_0 & 0 & 0 & 0 & D_1 & & & & \\
 & & D_0 & 0 & 0 & 0 & D_1 & & & \\
 & & & D_0 & 0 & 0 & 0 & D_1 & & \\
 & & & & D_0 & 0 & 0 & 0 & D_1 & \\
 & & & & & \ddots & & & & \ddots
\end{bmatrix}
$$

Figure 10: Example for the transition matrix when all message has a length of 5 cells and the minimum interarrival time is 1 time slot.