Flow Control and Routing of Bursty Traffic in Asynchronous Transfer Mode Systems

Victoria BOGHANASTJUK, Nicolae KOBILEATZKY
Technical University of Moldova, Automatic and Informational Technologies Department,
Stefan cel Mare av., 168, MD 2004, Chisinau, Republic of Moldova
Phone: (+373-22) 509911, fax: (+373-22) 509905
boghanastjukv@gmail.com

Abstract—**Asynchronous transfer mode (ATM) is currently being proposed as a transmission technique for future broad band integrated services networks. The traffic flow in ATM systems is decomposed into call burst and cell layers. An algorithm is derived witch routing tables according to changing load conditions. Each layer is governed by a different time scale and observers fluctuations of different entities. A solution method for feedback asynchronous systems then proposed is based on a generalization of the multicriteria shortest-path techniques for variable-structure network as well a on the reference points and reference trajectory approaches.**

Index Terms—**Communication networks, large scale systems, flow control, routing control, traffic estimation, multicriteria optimization shortest-path, methods optimal control**

I. INTRODUCTION

The asynchronous transfer mode (ATM) is being proposed as an information transfer technique for future integrated services digital networks [1-5]. Time behaviour of the ATM system is described by the following stochastic processes: number of calls connections $U_3(t)$, number of bursts in progress $U_2(t)$, number of cell arrivals $U_1(t)$, and number of the cells in the system $X(t)$. The state of the process $U_1(t)$ is conditioned on the state of process $U_2(t)$, and possibly, on the state of the process $U_3(t)$ and

$$P\{U_2(t)=U_1\}=\sum\sum P\{U_1(t)=U_1 \mid U_2(t)=U_2\},$$

$$P\{U_2(t)=U_2 \mid U_3(t)=U_3\}, P\{U_3(t)=U_3\}.$$

The system performance analysis is broken down into layers and an attempt is made to evaluate an impact of each layer on queuing and blocking. Define $\breve{U}_m$ as maximum number of entities in layer m, which can simultaneously be carried by the system. A time interval (t_a,t_b) such $U_m(t)>\breve{U}_m$ and $U_n(t)\le\tilde{U}_n$, $n=m+1,m+2,...,m$, $t\in(t_a,t_b)$, which be called an m-layer overload period. Denote by $\tilde{D}_m$ the total delay incurred by cells during overload periods in layer m and by $\tilde{U}$ the total number of cells arrivals. The delay is $\tilde{d}_m=\tilde{D}/\tilde{U}$. Mean delay $\tilde{d}$ suffered by cells in the multiplexer is given

$$\tilde{d}=\sum_{m=1}^{N}\tilde{d}_m . \tag{1}$$

The aggregated model of the flow in layer m will be constructed under an assumption that the number of active entries in layer m+1 is fixed an equal to the mean $\tilde{U}$, $\tilde{U}_{m+1}$. Denote by D_m the total delay incurred during overload periods in layer m determined from the aggregated model and $D_m>\tilde{D}_m$ that assumption allows one to treat quantities $\breve{d}=\sum_{i=1}^{M}\breve{d}_i$ and d=max{$d_1,d_2,\ldots,d_m$}.

Where $d_m=D_m \mid \tilde{U}$, as the lower and upper bounds on delay

$$\tilde{d}\le d\le\breve{d} . \tag{2}$$

The lower and upper bounds on blocking probability p can be defined in a similar way:

$$\breve{p}=\sum_{i=1}^{M}p_i,\ \breve{p}=\max\{p_1,p_2,...,p_m\},\ \tilde{p}\le p\le\breve{p} . \tag{3}$$

The source is described by specifying for each layer $m, m=\overline{1,M}$, two random variables: τ_m- interval time of m layer entries during an activity period in the m+1 layer, $\tilde{t}_{m+1}>>\tilde{t}_m>>t_{m-1}$, ν_m- m-layer entity duration and Δt – the basic observation interval, $\Delta t=TS_m\Delta t_{m-1}$. Where TS_m defines haw many m-1 layer time units constitute one m layer time, t- is absolute time. The state of arrival process at time t is described by random vector $U(t)=\{U_m(k_m)\}:k_m=k_m(t),m=\overline{1,M}\}$,

an evolution of the arrival process in layer m is described by the equation [5,6]:

$$U_m(k_m+1)=U(k_m)+A(k_m+1)-D(k_m+1) . \tag{4}$$

Where $A_m(k_m+1)$ is number of arrivals in layer m in epoch k_m ; $D_m(k+1)$ is number of departures in layer m in epoch k_m.

II. THE MULTILAYER MARCOV CHAIN (MLMC)

Define the channel utilization factor ρ_m in layer m during the activity period in layer m+1:

$$r_m=\frac{q_m}{q_m+p_m} .$$

q_m - denote a probability that an m-th layer entity arrives from a channel in a given epoch, provided that this channel is active in layer m+1, p_m - denote probability that m-th layer entity is completed. The mean number of active entities in layer m is $\tilde{U}_m = k\prod_{i=m}^{M} r_i$ in each layer the total channels utilization must be smaller than one $\tilde{U}_m \prod_{i=m}^{M} r_i < 1$, $\tilde{U} = \frac{1}{\prod_{i=m}^{M} r_i}$. Parameters of MLMC for packet voice are shown in table 1.Using the MLMC as a model of the input process gives the follow structural model of ATM system [7]:

$$U_3(k_3+1) = U_3(k_3) + A_3(k_3+1) - D_3(k_3+1). \quad (5)$$

Number of calls in progress:

$$U_2(k_2+1) = U_2(k_2) + A_2(k_2+1) - D_2(k_2+1). \quad (6)$$

Number of bursts in progress

$$U_1(k_1+1) = A_1(k_1+1). \quad (7)$$

The cells arriving in the lowest layer are put into the buffer state and the service process :

$$X(k_1+1) = X(k_1) + U_1(k_2+1) - Z\ (k_1+1). \quad (8)$$

buffer state :

$$Z(k_1+1) = \min[1; X(k_1) + U_1(k_1+1)] \quad (9)$$

where X(k_1)- the buffer content in epoch k_1 ;

Z(k_1+1) – the number of cells transmitted in epoch K_1+1.

TABLE1 PARAMETERS OF THE MLMC MODEL.

Layer / Parameters	Cell m=1	Burst m=2
TS_m	1	48
u_m	1	22
h_m	47	40.63
p_m	1	0.45
q_m	0.0213	0.2461
r_m	0.0208	0.3513

TABLE 2 SIMULATION RESULTS.

Parameters		Mean waiting time (msec)		
Nr of channel	Traffic intensity	Event by event simulation	Cell layer in aggregate model	Burst layer aggre-gate model
k	r_1		d_1	d_2
20	0.146	0.03	0.03	0.00
60	0.440	0.13	0.13	0.00
90	0.660	0.31	0.32	0.01
120	0.880	4.07	1.20	4.09
140	0.980	110.00	8.50	118.3

If $m < \breve{m}$ the mean number of arrivals in layer m seen in layer $\breve{m}$ during the mean number of arrivals in layer m seen in layer $\breve{m}$ during the interval $k_{\breve{m}}$, $k_{\breve{m}} = \overline{1, K_{\breve{m}}}$, can easily be determined

$$A_m(k_{\breve{m}}) = a(\breve{m}, m) U_{\breve{m}}(k_{\breve{m}}),\ k_{\breve{m}} = \overline{1, k_{\breve{m}}}.$$

(10) Where the constant $a(\breve{m}, m)$ is given by the formulas

$$a(\breve{m}, m) = \frac{\Delta t_m}{\bar{t}_m - 1} \prod_{i=m}^{\breve{m}-2} \frac{\bar{u}_{i+1}}{\bar{t}_i}. \quad (11)$$

Noting that $r_i = \bar{u}_i / \bar{t}_i$, it obtain

$$a(\breve{m}, m) = \frac{\Delta t_m}{\bar{t}_m - 1} \prod_{i=m+1}^{\breve{m}-1} r_i. \quad (12)$$

If $m > \breve{m}$ and the states of layer m changes slowly on the time scale $k_{\breve{m}}$ then $U_m(k_m)$ seen in layer $\breve{m}$ in time interval k_m , k_m and $k_{\breve{m}}$ being conjugate time epochs may be treated constant

$$U_m(k_m) = \bar{u}_m,\ k = \overline{1, k_m}. \quad (13)$$

Assume that $\breve{m}$ is the lowest modelled layer and that m=1. In the remainder of the paper we consider the following aggregated model:

$$U_{\breve{m}+1}(\breve{k}) = \breve{U}_{\breve{m}+1}. \quad (14)$$

arrival process in layer $\breve{m}$ +1:

$$U_{\breve{m}}(k_{\breve{m}}+1) = U_{\breve{m}}(k_{\breve{m}}) + A_{\breve{m}}(k_{\breve{m}}+1) - D_{\breve{m}}(k_{\breve{m}}+1). \quad (15)$$

The number of calls in the buffer and the number of transmissions in epoch $k_{\breve{m}}$ are determined according to the following dependencies:

$$X_{\breve{m}}(k_{\breve{m}}+1) = X(k_{\breve{m}}) + a(\breve{m}, 1) U_{\breve{m}}(k_{\breve{m}}+1) - Z_{\breve{m}}(k_{\breve{m}}+1). \quad (16)$$

$$Z(k_{\breve{m}}+1) = \min[\prod_{i=1}^{\breve{m}} TS_i; X(k_{\breve{m}}) + a(\breve{m}, 1) U_{\breve{m}}(k_{\breve{m}}+1)]. \quad (17)$$

Where $X(k_{\breve{m}}+1)$ is state, $Z(k_{\breve{m}}+1)$ is service process.

There are basically two state variables in that model, the number $U_{\breve{m}}$ of $\breve{m}$ layer entries in progress and the number X of cells in the buffer. $A_{\breve{m}}$, $D_{\breve{m}}$ are random variables witch change independently of other quantities.

The aggregated models can be implemented with the results of event by event simulation (Table 2). They are compared with results of event by event simulation. It was show that under an assumption of Poisson arrivals and exponential holding times a and d have following form: $d = \frac{1}{T}[1 - \exp(-T)],\ T = \Delta t / t.$

An correlation function of the process $\{X(k_{\breve{m}}), k_{\breve{m}} = \overline{1, K_{\breve{m}}}\}$ decays exponentially $a_k = \exp(-kT).$

III. FLOW CONTROL

The performed analysis indicates that in order to operate system efficiently the number of calls and burst in progress should be limited so as to avoid overload periods in corresponding layers [2]. Denote by $\bar{r}$ the critical load above witch overloads in the burst layer cause long delays and $r = u_2 r_1$ or $r = u_3 r_2 r_1$. Long delays and high cell blocking are avoided when

$$u_3 r_2 r_1 < \bar{r}. \tag{18}$$

Or alternatively

$$u_2 r_1 < \hat{r}. \tag{19}$$

In order to keep r below $\bar{r}$ various procedures can be used. They control the follow of entities in different layers.

Cell layer. Individual bits or cells are dropped. As a result, the channel utilization by cells in a burst, r_1, is then decreased, witch means that the total channels utilization $r = u_3 r_2 r_1$, is also decreased. Assuming the maximum number u_3 of calls, which are accepted by the system and the fixed density r_2 of bursts in a call, the critical value $\hat{p}_1$ of channel utilization by cells during a burst is obtained from the condition (18)

$$\hat{r}_1 = \frac{\hat{r}}{u_3 r_2}. \tag{20}$$

Burst Layer. In a similarly way we can clip or drop burst. It reduces r_2 and consequently $r = u_3 r_2 r_1$. The flow control policy which consists of blocking whole bursts keeps the number u_2 of bursts in progress below the threshold $\hat{u}_2$. The threshold value is obtained from the condition (19)

$$\hat{u} = \frac{\hat{r}}{r_1}. \tag{21}$$

Call layer. The call acceptance / rejection policy consists of rejecting new calls when the number of calls in progress is bigger than $\hat{u}_3$

$$\hat{u}_3 = \frac{\hat{r}}{r_1 r_2}. \tag{22}$$

One can simultaneously control the traffic flow in several layers.

Routing control scheme. The routing scheme is than presented witch defines traffic distribution at a network node. Link and node description are combined to give a network model. Routing at network nodes is done according to routing tables. Denote by N a set of network nodes : N= {I,j,k,…} and by L a set of network links : {(I,j),(j,k),…} by R_{jk} a path from node j to node l through node k, R_{jk}= {(j,k),(k,l)}. An algorithm of updating routing tables consists of following steps [3]:

Update an information I(k) about state of all links

$$I(k)=\{x_{jk}(k),U_{jk}(k) : (j,k) \in L\}. \tag{23}$$

1. Estimate traffic congestion $Z_{jk}(k+1)$ on links (j,k) in the approaching time interval

$$Z_{jk}(k+1)\Lambda_{jk}\{I(i), i=\overline{1,k}, \forall (jk)\in L \tag{24}$$

2. Determine qualities $W_{jk}^{l}[z(k)]$ of routes $R_{jk}^{l}; k\in N, k\neq j$ from j to l for all origin destination pairs $j,l\in N$.
3. For each origin j and destination l determine a sequence $\Psi_j^l(k)$ of overflow routes : by arranging them according to their quality

$$\Psi_j^l(k) = \{R_{jkm}^l(k), m=\overline{1,M_j^l}, k_m \in N, k_m \neq j\}. \tag{25}$$

We shall denote by $\overline{\Psi}(k)$ a set of overflow sequences:

$$\overline{\Psi}(k) = \{\Psi_j^l(k); j,l\in N. \tag{26}$$

Theorem.

Routes R_{jk}^l which are used by the traffic from origin j to destination l have the some length

$$W_{jk}^l(k) = \sum_{(u,v)\in R^l{}_{jk}} w_{uv}(k), (j,k)\in O(j). \tag{27}$$

$$w_{uk} = \frac{d\Phi_{uv}[X_{uv}(k+1)]}{dx_{uv}(k+1)}, (u,v)\in L \tag{28}$$

and are not longer than the unused routes. The function $w_{uv}(k)$ may be interpreted as the state dependent link length. The function Φ_{uv} is separable and described a quality functional. This solution can be implemented by means of the algorithm.

Proof. The routing control consists of avoiding the link saturation which is equivalent to a maximization of the function

$$\Phi_{uv}[X_{uv}(k+1)] = [m_{ux} - X_{uv}(k+1)]^2 \tag{29}$$

that the network links have finite capacities $m_{uv}, \forall (u,v)\in L.$ The control constraints now have the form

$$1 + Q_{jl}^l \geq 0, \tag{30}$$

$$Q_{jk}^l(k) \geq 0, (j,k)\in O(j), k\neq l. \tag{31}$$

$$\sum_{(j,m)\in O(j)} q_{jm}^l(k) = 0, \tag{32}$$

For all origin – destination pairs j, l∈ N. This (29) corresponds to the following form of the route length function for the alternates routes

$$w_{jk}^l(k) = -[w_{jk}(k) + w_{kl}(k)]. \tag{33}$$

For the direct routes obtain

$$w_{jk}^l(k) = -w_{jl}(k). \tag{34}$$

The link length function is given by

$$w_{uv}(k) = m_{uv} - X_{uv}(k+1), \forall (u,v)\in L. \tag{35}$$

Assume now that alternate routes $R_{jk_e}^l = \{(j,k_e),(k_e,l)\}, l=\overline{1,E_j^l}$ are used by the traffic from j to l in the time epoch k+1:

$$Q_{jk_e}^l(k) > 0, l=\overline{1,E_j^l}, \tag{36}$$

$$b_{jk_e}^l(k) > 0, l=\overline{1,E_j^l}, \tag{37}$$

$$w_{jkl}(k) + w_{\mathrm{Re}\,l}(k) = \frac{l_j^l(k)}{bu_j^l(k+1)}. \tag{38}$$

$$w_{jk}(k) + w_{kl}(k) \geq \frac{l_j^l(k)}{bu_j^l(k+1)}. \tag{39}$$

Here $l_j^l(k)$ - the Lagrange multipliers, b_{jl}^i, b_{jk}^i - the multipliers relate constrains. Using similar argument one check that if the alternate routes are used then for the direct route $r_j^l = \{(j,l)\}$.

$$w_{jl}(k) = \frac{l^l_j(k)}{bu^l_j(k+1)}. \tag{40}$$

Note that according to the definition (27) the left hand sides of (38)-(40) are the route lengths $w^l_{jk}(k)$.

IV. AGGREGATED OPTIMAL CONTROL PROBLEM FORMULATION AND SOLUTION

The following numerical structures constitute an input to the multicriteria shortest-path method:

1. A computer representation of the system's network $\Gamma = (Q,E)$, where $e = (q_1,q_2) \in E$ if there exists $s \in S$ such that $q_2 = d(s,q_1)$.

2. The control patterns $g_i, i = \overline{1,K}$ are called as a list of pointers $s_1,...s_{ni}$, to the operations forbidden after occurrence of the i-th operation and subsequent W(i)-th control pattern.

3. The criteria $F_1,...,F_M$ and $G_1,...,G_M$ are given as the matrices

$A_1 = [f_{ij}],\ i = \overline{1,K},\ j = \overline{1,M}$ with $f_{ij} = f_{1j}(s_i)a_i(q_0)$,

$A_2 = [m_{d\,ij}],\ i = \overline{1,K},\ j = \overline{1,M}$ with $m_{d\,ij} = m_{d\,j}(s_i)$,

and $A_3 = [d_{ij}],\ i = \overline{1,K},\ j = \overline{1,M}$ with $d_{ij} = d_j(s_i)$.

4. The preference relation an Q_m is represented by the values of the function $V = [V_1,...,V_L]$ on to elements of Q_m and stored in the array V. The reference trajectories are specified as lists of elements of Q. The proposed algorithm will be based on the method allowing the simultaneous evaluation of all optimal paths starting at q_0 and terminating at an element of Q_m. Same of difficulties which had to be solved were implied by the varying structure of G and the dependence of the coefficients of A_2 and A_3 on the control parameters previously implemented. A draft of this algorithm is presented below.

Algorithm 2.

Step1. Decompose the set Q into level sets $Q_1,..,Q_p$ so that q_0 canned be linked with an element of $Q_j,\ j = \overline{1,l}$ by a path consisting of less than j edges. Set $Q_0 = \{q_i\}, i = 1,2.$

Step 2. Compute the characteristics of the shortest paths beginning at q_0 and terminating at the elements of Q_1.

Step 3. For each $q \in Q$ find the set of transitions from q_i allowed by each of the control patterns $g_i = W(s_i, x_i)$, where s_i responsible for the transition from an element of Q_{i-1} to q and x_i is the i-th supervisor state.

Step 4. For each $r \in Q_{i+1}$ find the characteristic of the shorts paths terminating at r in the reduced network found in the previous step. To update the values computed for all the predecessors q of r from Q_i find in the array A_1 the appropriate values of $f_j(s_i,q)$ and calculate $g_i(g_i, g_{i-1}) = g_j(w(s_i), w(s_{i-1}))$,according to

$$g_i(g_i) = \sum_{j=1}^{k}[m_d(s_j)(1-g_i(s_j)) +$$
$$\max\{g_{i-1}(s_j) - g_i(s_j), o\}d(s_j)].$$

Step 5. If a marked state q_{mp} occurs at the i-th level then compute the values of the function m for all non – dominated paths terminating at q_{mp} and find the least – distance trajectory. The resulting criteria values (including m) and least-distance trajectory are then stored as the p-th columns in the A_2 and A_3 respectively.

Step 6. If the shortest-path characteristics for all elements of Q_m are stored in A_2 stop, otherwise repeat the step 3, 4, 5 for the incremental value of i.

V. CONCLUSIONS

The methods developed in this paper can be used to determine the critical channel board r so as to meet the user performance requirements the maximum cell blocking and the maximum delay where the maximum delay is determined by the buffer size. The matrix multiplications were used to obtain the numerical instability which characterize the methods. This have derived the algorithm which up date routing tables in circuit switching networks according to the changing traffic conditions The algorithm is based on realistic assumptions about the structure of control and available system status information.

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