1 Introduction

The ATM computer network consists of switches, sources and destinations of the transported data. The ATM network is based on switching packets of the same length called cells. Switches can transmit packets from their input to their output and also get information about the intensity of the traffic. Network traffic management is a significant process used for proper functioning of the network. The traffic management is based on a specific algorithm. To avoid congestion, current ATM networks use techniques of timeout, duplicate acknowledgement or explicit congestion notification.

For monitoring the state of the network, special cells called RM (Resource Management) are used in the ATM network. RM cells inform data sources about the maximum rate of flow acceptable by the network. The traffic management is based on a specific algorithm. To avoid congestion, current ATM networks use techniques of timeout, duplicate acknowledge or explicit congestion notification.

For monitoring the state of the network, special cells called RM (Resource Management) are used in the ATM network. RM cells inform data sources about the maximum rate of flow acceptable by the network. The load of the network varies in time, and interference of different loads in the same point can cause congestion. When this happens, the memories of the switches are overloaded and incoming cells have to be refused, i.e. removed. In this paper a new method is proposed for an earlier reaction to congestion.

An analytical model of a switch was constructed for an analysis of the network behaviour. This model is used for analysing traffic through the network. A description of the model is given in the sections below.

1.1 Standard traffic management

There are several classes of traffic in the ATM network. This paper considers the class called Available Bit Rate (ABR), used for transmitting files.

The ABR class of ATM computer networks uses feedback information on data transport from switches and destination to the source to control the load. The feedback mechanism is essential for good throughput of networks enabling an earlier reaction of sources when congestion of switches occurs.

The transported data are arranged in packets of cells. These packets have the same length, and a special cell called the RM cell precedes every packet. The traffic management is based on RM cells. RM cells pass from the source to the destination and collect information about the maximum rate of generated load which is acceptable by a dedicated path. After their acceptance by the destination they are sent back in order to bring the feedback information to the source. The rate of the traffic load is adjusted in the source according to the value received from the RM cell.

The flow of data cells together with RM cells between switches SW(i) and SW(i+1) is shown in Fig. 1. The RM cells are pictured as black rectangles, and the other cells as white rectangles. The packets of data cells with the RM cell number 8 are sent from the data source, i.e. forwards. Only RM cells 2 and 3 are sent backwards to bring feedback information from the destination.

![Fig. 1: The flow of counted RM cells](image)

The disadvantage of this method is that the source of data obtains information about the current rate of the load, but it does not know which particular data was lost because it was refused within the switches. This information can be obtained later from the destination. In other words, RM cells always have to go along the whole path from the data source to the destination and back, see Fig. 5, 7.

1.2 Proposed traffic model

In the proposed model all RM cells are numbered by the source. The RM cells are returned by the switches at the moment of their congestion. If congestion occurs, the packets are refused. But associated RM cells are immediately sent back to inform the source of the loss of data. In this model, the source is informed earlier about the congestion in the network because RM cells did not pass along the whole path, see Fig. 5, 8.

2 Analytical model of the switch

In this part the behaviour of basic network components – switches – is studied. The behaviour of the switch can be described as a stationary queuing process. Let $M|M|1|m$ be a queueing process according to the Kendall notation.
The symbols denote:

\( M \) – distribution function of the cell interarrival time is exponential with the mean \( \lambda \), \( 0 < \lambda < \infty \) and the arrival times are independent;

\( m \) – system of queue length \( m \);

\( m+1 \) – system with one place in service;

\( m \) – system of queue length \( m \).

Notation used in the following text:

\( \lambda \) – average arrival intensity;

\( \mu \) – average service rate;

\( \rho = \lambda/\mu \) – traffic intensity.

Let us assume that cells coming to switch are stored in a switch queue of length \( m \). Cells are refused if all of the \( m \) waiting places are occupied, and further arriving cells are cancelled. The situation is shown in Fig. 2. The cell with index 0 is being transmitted and the following cells are waiting in the queue. The other incoming cells with an index equal to or greater than \( m+1 \) are refused.

Fig. 2: The structure of a switch

<table>
<thead>
<tr>
<th>REFUSED CELL</th>
<th>WAITING CELLS</th>
<th>CELL IN SERVICE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \cdots )</td>
<td>( m )</td>
</tr>
<tr>
<td>( m+1 )</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3 shows the dependence of probability \( p_z \) for \( \rho \neq 1 \) and \( \rho = 1 \) on the value \( m \) for several values of traffic intensity \( \rho \).

We can also use the probability of service \( P_p \)

\[ P_p = 1 - p_z. \tag{4} \]

Other formulas describing the behavior of the queueing system can be found in [5].

The behavior of the system for values of traffic intensity \( \rho \) close to 1 will be studied. In this case the refusal of cells occurs more frequently.

### 3 Path of cell transport

It is supposed that a path of cell transport from source \( S \) to destination \( D \) includes a sequence of \( n \) switches \( SW(i) \), \( 1 \leq i \leq n \). The same path is used for both forward transport of data cells together with RM cells and backward transport of RM cells. In the backward transport the RM cells pass through the switches in the reverse order. The switches are marked \( SW(i) \), \( n+1 \leq i \leq 2n \). Both paths are shown in Fig. 5.

The following notation is used in Fig. 5:

\( S \) – source of cells;

\( D \) – destination of a transport;

\( SW(i) \) – \( i \)-th switch in the path;

\( t_i \) – time period needed for cell transport along the line connecting switches \( SW(i) \) and \( SW(i+1) \).
3.1 Characterization of cell transport

The following cases of cell transport from the source to the destination were studied:

- The data cell is transported without being refused.
- The data cell is just once refused during the transport.

The formulas for transport time will be stated below, and we will use the weighted averages of the mean values of these time periods to compare the two models. We choose the probabilities of possible events as weight coefficients.

We do not consider the other cases of cell transport (when the number of refusals is greater than 1) because earlier studies [1, 2] have shown that the associated probabilities are negligible. The probabilities of cell refusal in a switch are denoted by the symbols {0, 1, ..., n} and we calculate their values can be approximated:

\[ P_0, P_1(i), i = 1, ..., n \]

We use the values \( P_0, P_1(i), i = 1, ..., n \) as the probabilities of the events \( \{0, 1, ..., n\} \).

We note that \( P_0 + \sum_{i=1}^{n} P_1(i) = 1 \).

We consider the individual cases of the cell transport denoted by the symbols \( \{0, 1, ..., n\} \) and we calculate their transport time.

We denote:

- \( T_{s1} \) total time period of cell transport in the standard model;
- \( T_{s0} \) total time period of cell transport without refusal in the standard model;
- \( T_{s1}(i) \) total time period of cell transport with refusal in the i-th switch in the standard model;
- \( T_{p1} \) total time period of cell transport in the proposed model;
- \( T_{p0} \) total time period of cell transport without refusal in the proposed model;
- \( T_{p1}(i) \) total time period of cell transport with refusal in the i-th switch in the proposed model.

3.2 Cell transport without refusal

The value \( P_0 \) is the probability of cell transport without refusal within any switch of the path. It is actually the probability of a successful transmission without loss of any cell.

The influence of the proposed modification does not appear in this case and the transport times in the standard and proposed models are the same. In both models cells pass along the whole path from source \( S \) to destination \( D \). This path is shown in Fig. 6.

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The mean value of time $T_{31}(0)$ and $T_{3h}(0)$ is

$$E(T_{31}) = E(T_{3h}) = n\sum_{k=1}^{n-1} t_k + n\sum_{k=1}^{n} E(W(k)).$$

(7)

because only time periods $W(k)$ are random quantities.

### 3.3 Cell transport with refusal of cells in the standard model

We calculate the transport time $T_{31}(i)$. The assumption is that a cell is refused in the $i$-th switch $SW(i)$. The destination must call for repeated sending of the refused cell. The probability $P^1(i) = \rho_i(i)$ of this case is given in (5).

The path of a cell transport in the standard model is shown in Fig. 7. The switch $SW(i)$ is congested and that is why a cell is refused. Information about a cell being refused is not known before an uncompleted packet is received by destination $D$. Such a situation results in a request for a repeated transmission of data cells until the complete packet arrives at its destination.

![Fig. 7: Path of a cell transport with refusal in the standard model](image)

The cell and the request have to pass the path three times and the total time period needed for the cell transport $T_{31}(i)$, $i = 1, \ldots, n$, is

$$T_{31}(i) = 2 \sum_{k=1}^{n-1} t_k + n \sum_{k=1}^{n} W(k).$$

(8)

The mean value of the time period $E(T_{31}(i))$ is

$$E(T_{31}(i)) = 2 \sum_{k=1}^{n-1} t_k + n \sum_{k=1}^{n} E(W(k)) + \sum_{k=n+1}^{2n-2} t_k + \sum_{k=n+1}^{2n} W(k).$$

(9)

### 3.4 Cell transport with refusal of cells in the proposed model

In the proposed modification, the cell transport path and the associated request are shown in Fig. 8. The request for the repeated sending is sent immediately from the congested switch $SW(i)$. We can see that in this case the cell and the associated request for its repeated sending does not very often pass along the way from the source to the destination.

![Fig. 8: Path of a cell transport with refusal in the proposed model](image)

The cell is refused in the $i$-th switch with the probability $P^1(i) = \rho_i(i)$.

The time periods needed for the transport along the individual parts of the whole path are:

1. $\sum_{k=1}^{i} t_k + \sum_{k=1}^{i-1} W(k)$

This is the time period of cell transport from source $S$ to switch $SW(i)$:

2. $\sum_{k=2n-i+3}^{2n+2} t_k + \sum_{i=1}^{k=2n-i+2} W(k)$

This is the time period needed for transmission of the repeated sending request from switch $SW(i)$ to source $S$.

3. $\sum_{k=1}^{n+1} t_k + \sum_{k=1}^{n} W(k)$

This is the time period needed for transport of the cell from source $S$ to destination $D$.

The total time period $T_{31}(i)$ needed for the transport is:

$$T_{31}(i) = \sum_{k=1}^{i} t_k + \sum_{k=1}^{i-1} W(k) + \sum_{k=2n-i+3}^{2n+2} t_k + \sum_{k=2n-i+2}^{2n} W(k) + \sum_{k=1}^{n+1} t_k + \sum_{k=1}^{n} W(k).$$

(10)

The mean value of time period $E(T_{31}(i))$ is

$$E(T_{31}(i)) = \sum_{k=1}^{i} t_k + \sum_{k=1}^{i-1} E(W(k)) + \sum_{k=2n-i+3}^{2n+2} t_k + \sum_{k=2n-i+2}^{2n} E(W(k)) + \sum_{k=1}^{n+1} t_k + \sum_{k=1}^{n} E(W(k)).$$

(11)

### 4 Comparison of cell transports

We now compare the total time period of the cell transport in the standard model and in the proposed model. The transport time in the individual cases denoted by index $\{0, 1, \ldots, n\}$ are random variables and the corresponding probabilities $P^0(i)$, $P^1(i)$ are given in (5). As the mean value of the total transport time periods $T_{31}$ and $T_{3h}$ we use the weighted averages of mean values $E(T_{31}^0)$, $E(T_{31}^1)$ and $E(T_{3h}^0)$, $E(T_{3h}^1)$. The coefficients of weighted averages are the probabilities $P^0(i)$, $P^1(i)$.

If we denote by $E(T_{31})$ the mean value of the total time period of the cell transport in the standard model and by $E(T_{3h})$ the same quantity in the proposed model, we obtain:

$$E(T_{31}) = E(T_{31}^0)P^0 + \sum_{i=1}^{n} E(T_{31}^1(i))P^1(i).$$

$$E(T_{3h}) = E(T_{3h}^0)P^0 + \sum_{i=1}^{n} E(T_{3h}^1(i))P^1(i).$$
The effect of the modification of the standard model is expressed by the difference
\[ E(T_s^1) - E(T_h^{0}) = \left[ E(T_s^0) - E(T_h^{0}) \right] p^0 + \]
\[ + \sum_{i=1}^{n} \left[ E(T_s^1(i)) - E(T_h^{1}(i)) \right] p^1(i) = \]
\[ = \sum_{i=1}^{n} \left[ E(T_s^1(i)) - E(T_h^{1}(i)) \right] p^1(i) = \] (12)

where we use the equality (7) \( E(T_s^0) = E(T_h^{0}) \). The values \( E(T_s^1(i)) \) and \( E(T_h^{1}(i)) \) are given in (9), (11). The last expression depends on many parameters. We determine its value for one simple case. In the sequel we assume that the switches are identical, i.e. the waiting times \( W(k) \) are the same and times \( t_k \) are equal.

We denote:
\[ E(W) = E(W(k)), 1 \leq k \leq 2n; \]
\[ p_z = p_z(k), P_p = P_p(k), 1 \leq k \leq 2n. \]

In this case we get
\[ E(T_s^1(i)) = \left[ (3n + 3)\Delta t + 3n E(W) \right], \]
\[ E(T_h^{1}(i)) = \left[ (n + 2i + 1)\Delta t + (n + 2i - 2)E(W) \right], \]
\[ i = 1, \ldots, n. \]
\[ E(T_s^1) - E(T_h^{1}) = \]
\[ = 2p_z \sum_{i=1}^{n} [(n + 1 - i)(\Delta t + E(W))] = \] (13)
\[ = n(n + 1)p_z(\Delta t + E(W)). \]

The value \( E(T_s^1) - E(T_h^{1}) \) depends on the parameters of the switch \( (E(W), p_z) \) and the value \( \Delta t \). We can suppose that the values \( \Delta t \equiv E(W) \) and therefore the comparison of the two models is demonstrated by the expression
\[ V = p_z E(W) n(n + 1). \]

The values \( p_z, E(W) \) and \( P_p \) are defined in (2), (3), and (4). The following table contains the values of \( V \) for some path transport parameters.

Figs. 9 and 10 show the dependence of \( V \) on the number \( n \) of the switches for several values of traffic intensity \( \rho \). Fig. 11 shows this dependence for several values of buffer storage \( m \) and traffic intensity \( \rho = 1 \).

The value of expression \( V \) depends on the product of the probability \( p_z \) and the mean value of the waiting time \( E(W) \). Figs. 12 and 13 show the dependence of the product \( p_z E(W) \) on value \( m \) for several values of traffic intensity \( \rho \).

### Conclusion

The influence of the proposed modification of cell transport in an ATM computer network is tested. Analytical models of cell transport through standard and proposed modification are described. Formulas for the time period needed for cell transport for both models are presented.
A comparison is made by the weighted averages of the mean values of the time period needed for cell transport $E(T_{s_t})$, $E(T_{p_t})$. As the coefficient of weighted values, we choose the probabilities of particular cases. We assumed transports without refusal and with one refusal only.

The differences of the mean values $E(T_{s_t})$ and $E(T_{p_t})$ (13) are approximated by the expression $V$. Its values in Table 1 and the graph dependences in Figs. 9, 10 and 11 show that the effect of the proposed modification grows with increased values of traffic intensity $\rho$. From Table 1 and Fig. 12, 13 it follows that if traffic intensity $\rho < 1$, then the effect of the proposed modification decreases with increased values of buffer storage size $m$ while for $\rho \geq 1$ the effect of the proposed modification grows. This is caused by the fact that when $m$ increases, then the probability $p_z$ of cell refusal decreases, but for $\rho \geq 1$ the mean of the waiting time $E(W)$ increases faster, hence the product $p_z E(W)$ increases. If $\rho < 1$ then this does not happen. We see from Tab. 1 that in this case the effect of the modification actually becomes smaller as we increase $m$.

References


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