ASYNCHRONOUS ADAPTIVE SWITCHING

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Adaptive switching (AS) is a hybrid switching procedure which combines transmission with trunk capacity assignment, or circuit switching (CS) and store and forward transmission, or packet switching (PS). Adaptive switching features adaptive trunk capacity redistribution between the CS and PS modes adapted to the traffic load, and transmission of packet-mode data in-between CS messages. This paper discusses an AS version with simpler implementation made possible by using asynchronous variable-length rather than synchronous fixed-length frames. The proposed approach relies on alternate CS and PS frame transmission.

1. INTRODUCTION

Integrated services digital networks (ISDN) which are to support both CS and PS transmission have given a new impetus to research aimed at combining CS and PS [1, 2]. This paper addresses the approach, whereby hybrid switching is viewed as transmission of asynchronous variable-length [5] rather than synchronous fixed-length frames as in [3, 4]. In this context asynchronous transmission is restricted to frames and does not apply to bit transmission. Asynchronous frame transmission is typically employed to support PS traffic and offers a number of advantages, notably high trunk capacity utilization. Its principal limitation is the effect of the network traffic load on packet transmission delay and no upper bound for this delay. The approach discussed in the paper combines transmission modes equivalent to CS and PS to exploit the advantages of PS transmission and eliminate the above limitation.

Section 2 is a general description of asynchronous adaptive switching (AAS) and Section 3 evaluates its performance.

2. DEFINITION OF ASYNCHRONOUS ADAPTIVE SWITCHING

An AAS trunk transfers from station to station a sequence of variable-length frames with a fixed maximum length. All frames fall into two classes referred to below as circuit-switched (CS) and packet-switched (PS). Denote the maximum frame length as $L_{max}^{cs}$ and $L_{max}^{ps}$ (bytes) for CS and PS frames respectively. Either class of frames can make up a sequence and thus a succession of several CS frames can be followed by a number of PS frames. The maximum number of frames of either class that can be transmitted
continuously while the network station has data of the other class ready for transmission, is limited by the parameters $N_{\text{CS}}^{\text{max}}$ ($N_{\text{PS}}^{\text{max}}$) which denote the maximum number of CS(PS) frames that can be transferred continuously if the station holds data of both classes. The pair ($N_{\text{CS}}^{\text{max}}$, $N_{\text{PS}}^{\text{max}}$) will be referred to as the multiplex mode. If the station holds data of one class only (CS or PS) the frame sequence length for the corresponding mode may be unlimited.

CS transmission requires the establishment of a connection. A CS connection assigns a transmission route to the call and each trunk reserves for a connection $i$ $m_i$ data positions (bytes) out of the total $N_{\text{CS}}^{\text{max}}$ $M_{\text{CS}}^{\text{max}}$. If a new connection $j$ requires $m_j$ bytes it can be set up only if $N_{\text{CS}}^{\text{max}}$ $M_{\text{CS}}^{\text{max}} - \sum_{i \in I} m_i \geq m_j$, (2.1)

$I$ is the set of numbers (i) of all circuits set up earlier, and $M_{\text{CS}}^{\text{max}}$ is the maximum number of information bytes in a CS frame.

If condition (2.1) is not met a request for call set-up over a given trunk is rejected. A frame sequence which includes $N_{\text{CS}}^{\text{max}}$ maximum-length CS frames and $N_{\text{PS}}^{\text{max}}$ maximum-length PS frames will be called a maximum-length AS frame and denoted $F_{\text{AS}}^{\text{max}}$. Its length $L_{\text{AS}}^{\text{max}}$ is defined as $L_{\text{AS}}^{\text{max}} = N_{\text{CS}}^{\text{max}} L_{\text{CS}}^{\text{max}} + N_{\text{PS}}^{\text{max}} L_{\text{PS}}^{\text{max}}$, (2.2)

$L_{\text{CS}}^{\text{max}}$ ($L_{\text{PS}}^{\text{max}}$) is the maximum length of a CS(PS) frame respectively including the service data. In the discussion below we will use the parameter $f$ to denote the minimum permissible transmission rate for maximum-length AS frames.

Each network trunk $r$ must satisfy the constraint $f_r^{\text{AS}} \geq f$, (2.3) where $f_r^{\text{AS}}$ is the transmission rate for maximum-length AS frames over trunk $r$. For each trunk $r$ with a transmission rate $C_r$ the constraint determines the maximum AS frame length $L_r^{\text{AS}} \leq C_r f_r$, (2.4)

where $L_r^{\text{AS}}$ is the maximum frame length (bytes) for the trunk $r$ and $C_r$ is the transmission rate (bytes/s), over the trunk.

CS and PS frames have the same format. The header and the end-of-frame sequence are consistent with the data link layer procedure adopted for frame transmission over a given trunk, e.g. HDLC or a simpler data frame transmission procedure with no flow control or frame retransmission, and so on.

The information field of the frame is formatted to match the type of information to be transmitted. It may include a service packet (s) and/or a data field (s) and its structure may follow that of X 25/3 packets (Fig. 2.1).

AS data can be transmitted in 3 different modes: a) packet switching where the data block is the data unit of a data packet; b) circuit switching with error checking (CSC) where the data block is a sequence of characters transmitted in the CS mode (CSC frames).

If a frame is found to be in error it is retransmitted; c) circuit switching with no error checking (CSN) where data blocks are formatted as in (b). However if a frame is found to be in error it is not retransmitted and the data blocks are transmitted to their destination, if possible.

The transmission mode (PS, CSC, or CSN) is defined by the number of the logical link group. Thus, logical link group 0000
may be reserved for CSC, 0001 for CSN and the rest of the link supports PS transmission. The PS mode can use several priority classes distributed among the link groups. The information field of a frame may include data blocks of one type only: PS blocks of equal priority, CSC or CSN blocks. The type of information fields contained in an AS frame is defined by its frame identifier.

Virtual and switched circuits differ mainly in the call set-up procedure. A virtual connection is set up in a conventional manner defined by X25/X75.

Switched circuits (CSC or CSN) are set up with some part of the trunk capacity between adjacent network stations assigned to the connection. This is achieved by reserving out of the total of \( N_{\text{max}} \) positions, \( m \) data positions needed for the connection to be made with the required transmission rate.

Thus, if the required transmission rate and the minimum AS transmission rate are \( R \) bytes/s and \( f \) frames/s respectively, the number of data positions (bytes) \( m \) reserved for the relevant connections should be \( m = \frac{R}{f} \) (2.5). Switched circuits can be set up only subject to (2.1).

### 3. EVALUATION OF AS NETWORK PERFORMANCE

This section discusses several qualitative characteristics of the AS network trunk as related to the transmission requirements.

#### 3.1. Minimum Frame Transmission Rate

The minimum AS frame transmission rate \( f_0 \) depends on the maximum permissible period between any two successive transmissions \( T_{\text{per}} \) in a given network. This parameter is related to the requirements of the data sources or the period of data accumulation that must be followed by data transmission. Generally \( f_0 = \frac{1}{T_{\text{per}}} \) (3.1).

#### 3.2. Maximum CS Transmission Delay

Consider a trunk which transmits at \( C \) bites/s. Also assume that the trunk traffic consists of AS frames defined by the parameters \( N_{\text{CS}}, N_{\text{PS}}, L_{\text{CS}} \), and \( L_{\text{PS}} \). Given these parameters we can evaluate the maximum delay \( T_{\text{CS}} \) to be exceeded by the actual delay in CSN transmission.

Two traffic alternatives are assumed:

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Fig. 2.1. Information Field Format in Data Block Transmission

<table>
<thead>
<tr>
<th>Logical link number</th>
<th>Logical group number</th>
<th>P(R)</th>
<th>M</th>
<th>P(S)</th>
<th>Data block length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 1 0 1</td>
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<td>Logical group number</td>
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<td>Data block</td>
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</tbody>
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2.3B.6.3
a) Relatively even traffic: no more than $M_{CS}^{\text{max}}$ bytes of CS data can arrive at a station while a CS frame is being transmitted; 
b) Heavily uneven traffic: $M_{CS}^{\text{max}}$ bytes of CS data can arrive at a station while a CS frame is being transmitted. In (a) the delay will be maximal if all CS blocks arrive at the beginning of the last CS frame in a sequence of $N_{CS}^{\text{max}}$ frames prior to the PS frame sequence. In this case

$$\sigma^{\text{max}}_{CS}(N_{CS}^{\text{max}}, N_{PS}^{\text{max}}) = \frac{2r_{CS}^{\text{max}} + N_{PS}^{\text{max}}r_{PS}^{\text{max}}}{C}$$ \hspace{1cm} (3.2)

In (b) the maximum delay may be

$$\sigma^{\text{max}}_{CS}(N_{CS}^{\text{max}}, N_{PS}^{\text{max}}) = \left( \frac{N_{CS}^{\text{max}} + 1}{N_{PS}^{\text{max}}} \frac{L_{CS}^{\text{max}} + L_{PS}^{\text{max}}}{\text{bytes}} \right) / C \hspace{1cm} (3.3)$$

Example 1. Variation of maximum CSN delay with trunk transmission rate. Assume that a maximum-length PS frame contains 128 data bytes and its total length is 138 bytes including redundancy. Let the maximum CS data block length be 32, 16 or 8 bytes. Also assume that a CS frame can contain up to 4 multiplexed maximum-length CS blocks and the CS frame length $L_{CS}^{\text{max}}$ for the block lengths given above is 147, 83, or 51 bytes respectively. A CS frame can contain more CS blocks of shorter length provided the overall frame length is within $L_{CS}^{\text{max}}$ bytes. A PS frame can hold one maximum-length packet and the overall frame length $L_{PS}^{\text{max}}$ is then 138 bytes. The frame can accommodate several shorter packets provided its overall length is $L_{PS}^{\text{max}}$ bytes or less.

**Fig. 3.1.** Maximum CS Transmission Delay vs Transmission Rate

In a given multiplex mode the value of $N_{CS}^{\text{max}}$ is limited by (3.1) which implies that for a given trunk transmission rate the time taken to transmit an AS frame of $(N_{CS}^{\text{max}}L_{CS}^{\text{max}} + N_{PS}^{\text{max}}L_{PS}^{\text{max}})$ bytes is at most $T_{\text{per}}$ per. Thus, if $T_{\text{per}} = 0.1$ s and the transmission rate is 64 kbits/s no AS frame should be more than 6.4 kbits or 800 bytes long. Hence, in the multiplex mode $(N_{max}^{\text{max}}, I)$ the total length of a sequence made up of $N_{CS}^{\text{max}}$ CS frames $L_{CS}^{\text{max}}$ bytes long each should not be in excess of 800-138=662 bytes. Hence, for $L_{CS}^{\text{max}} = 147$, $N_{CS}^{\text{max}}$ cannot exceed 4, for $L_{CS}^{\text{max}} = 83$ the value of $N_{CS}^{\text{max}}$ should be 8 or less, and so on.
3.3. Mean PS Transmission Delay

In the discussion that follows a network trunk with capacity \( C \) is assumed to carry CS sequences of \( N_{CS} \) CS frames \( L_{CS} \) long. Assume that each frame can multiplex \( n_{CS_{\max}} \) CS blocks and the trunk can thus support up to \( n_{CS_{\max}} = N_{CS_{\max}} \cdot n_{CS} \) CS calls. Bearing this in mind we will assume that the average capacity per CS call is

\[
C_{CS} = \frac{N_{CS_{\max}} \cdot L_{CS_{\max}} \cdot C_{PS}}{N_{CS_{\max}} \cdot L_{CS_{\max}} + N_{PS_{\max}} \cdot L_{PS_{\max}} + n_{\max}_{CS}} \quad \text{bytes/s} \quad (3.4)
\]

With allowance for inter-message pauses one circuit actually uses \( C_{CS}(1-h) \) bytes/s where \( h \) is the proportion of pauses between CS messages. Given a CS call request rejection probability \( P_{\text{rej}} \) the mean proportion of circuits that are actually engaged for CS transmission is \( \rho_{CS} = f(P_{\text{rej}}, n_{CS_{\max}}) \) and can be found from well-known relationships of queueing theory. With \( \rho_{CS} \) given, the mean trunk capacity available for PS transmission can be written as

\[
C_{PS} = \frac{N_{PS_{\max}} \cdot L_{PS_{\max}} \cdot C_{PS}}{N_{CS_{\max}} \cdot L_{CS_{\max}} + N_{PS_{\max}} \cdot L_{PS_{\max}}} + n_{\max}_{CS} \cdot C_{CS} \cdot (1-\rho_{CS}) + n_{\max}_{CS} \cdot C_{CS} \cdot \rho_{CS} \cdot h \quad (3.5)
\]

The first term defines the capacity assigned to PS in accordance with the multiplex mode adopted. The second term defines the mean CS capacity idle because of the call-request rejection probability constraint. The last term is the CS capacity idle due to the inter-message pauses in CS calls. With \( C_{PS} \) given and some assumptions, one can estimate the mean PS delay and other PS parameters. Thus, it is well-known that if a) the packet flow follows a Poisson distribution, b) the packet handling time is exponential and c) the queue length is infinite

\[
\tau_{\text{PS}} = \frac{\tau_{P}}{1 - \rho_{PS}} \quad (3.6)
\]

where \( \rho_{PS} \) is the capacity utilization factor in the PS mode and \( \tau_{P} \) is the mean packet transmission time. Assuming that packet transmission always uses the capacity \( C_{PS} \), we have

\[
\tau_{P} = \frac{L_p}{C_{PS}} \quad (3.7)
\]

where \( L_p \) is the average packet length. For constant packet transmission time

\[
\tau_{PS} = \frac{\tau_{P}(2 - \rho_{PS})}{2(1 - \rho_{PS})} \quad (3.8)
\]

Consider a numerical example that draws on the results of the example in Section 3.2.

**Example 2. PS Transmission Delay**

Assume that the pauses account for 0.6 of the total time or \( h = 0.6 \). By virtue of (3.4), the average capacity per CS connection in a 64 kbit/s trunk is \( C_{CS} = 207 \) bytes/s = 1656 bit/s. The mean PS capacity is by virtue of (3.5) \( C_{PS} = 6090 \) bytes/s. The discussion above suggests that although the trunk can support up
to 32 circuits with a transmission rate of about 1600 bits/s each the greater part of its capacity on average remains available for PS transmission. The average PS frame transmission time is defined as $\tau_p = 0.0226s$. The mean packet delay for a constant packet length is presented in Fig. 3.2. The same figure depicts maximum CS delay $\tau_{CS \max}$ for the same conditions in the multiplex mode $(N_{CS}^\max, N_{PS}^\max) = (8.1)$ and $(8.0)$ and the mean delay $\tau_{PS \min}$ for "pure" PS transmission with no circuit switching. It is seen that combined CS and PS contributes to efficient network capacity utilization and can support real-time transmission. A 2048 kbit/s trunk can carry 30 multiplexed 64 kbit/s circuits and a packet flow that can use on the average more than half the trunk transmission capacity. This will reduce transmission delay by a factor of several dozen.

CONCLUSIONS

Asynchronous adaptive switching makes it possible to combine store-and-forward transmission and capacity pre-assignment over the transmission route or, equivalently, packet switching and a mode similar to circuit switching. The first mode can be used to support traffic not critically sensitive to delay, and the second, real-time message transmission.

CS and PS frames are formatted alike and can be switched within the station by either hardware or software. This approach offers a basis for the design of high-throughput switches, specifically ISDN stations.

REFERENCES