Performance Comparison of Slotted and Partitioned Frame MAC Protocols of High Speed Ring Networks for Circuit- and Packet Switching

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Abstract

On high speed ring systems, the integration of circuit and packet switched services can be achieved by defining a synchronous pulse frame, partitioned either into two parts or into several time slots. Various strategies to combine both traffic types are presented and investigated by means of simulations. The mean waiting times for a PS message are compared for these principles and in case of the minipacket system also unbalanced loaded stations are investigated.

1 Introduction

Within the field of inhouse communication, new services, offered by new equipment, demand fast and flexible communication systems. Though the characterization of future services seems to be very difficult, new communication systems should now be designed to cope with this challenge. Neither the standardized local area networks (LAN) nor ISDN-PBXes offer the flexibility to cover all the new services and applications which may come up in the future.

New proposals for local area networks aim at the integration of the two basic switching principles, circuit switching (CS) and packet switching (PS). Providing both transmission services within one system easily allows every specific service the use of the appropriate switching principle without conversion. The first applications of this idea can be found on integrated links, but recently, the next generation of local area networks is based on the same integration principle. Typically, a ring system with a synchronously circulating pulse frame is common for all these approaches, and in most cases they are designed to be easily interconnected to cover the range of a metropolitan area network (MAN).

The different MAN proposals for integrated CS and PS can be classified in
• systems using a completely slotted frame (e.g. [3]) and in
• systems where the frame is partitioned into a part for CS traffic and one for PS traffic. (e.g. [4]). In general, within the CS part a time slot structure is used, too.

CS traffic is assigned to one or several time slots during a call set-up procedure, providing a guaranteed bandwidth for this traffic type. Depending on the number of time slots used by a connection, the bandwidth may be adopted to the requirements of the actually used service (Multi Rate CS). Interfacing such systems to the public ISDN leads to the use of 64 kbps for one basic CS channel.

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2 Integration Principles

2.1 Partitioned Frame

The first category of integration principles is based on partitioning of the pulse frame into a part for CS traffic and one for PS traffic. The access to this single PS channel has to be controlled by a suited protocol. To allow a fair distribution of the available bandwidth, a token passing scheme has been selected. But in contrary to the well-known IEEE 802.5 standard, a timer controlled multiple token protocol is necessary for the systems studied. The integrated CS part requires a relatively long round trip delay on the ring. Therefore, the token has to be released by the sending station immediately after the packet has been sent. This mechanism is used also by the ANSI high-speed token ring, the FDDI (Fiber Distributed Data Interface, [5]).

The boundary between the CS and the PS part may be fixed, resulting in two independent subsystems which are only multiplexed on one medium but without any mutual influence. Both parts of such a system may be analysed separately. Although there are no problems in managing this simple integrated system, the main drawback arises under varying traffic loads. For example, a high CS traffic load has to be cut down to the preset CS capacity even if the PS part is lightly loaded; no adaptation to varying load conditions is possible.

Improving the performance of such an integrated system is possible by moving the boundary between the CS and PS part. The actual position results from the momentarily CS occupancy pattern: the PS part immediately starts after the last time slot assigned to a CS connection. After clearing down a CS connection two modes are possible: either the existing CS connections remain in the time slots assigned at call set up and the empty slots are used only for new calls, or all empty slots are shifted towards the PS part of the pulse frame, allowing the boundary to be moved on every released CS connection. But in this case the existing CS connections have to be rearranged, which may cause some management problems in a distributed system like this one.
On the contrary, in the first case without rearrangement of existing calls, the boundary can be moved only after that call directly located next to the boundary is cleared down. The normal operation without any time slot rearrangement will cause unused slots within the CS part. This blocked bandwidth can be calculated by using the results by Coffman et al. [6] to obtain the location of the boundary. For systems with more than 50 Erl CS traffic approximately 15% more bandwidth is wasted by unused and blocked slots within the CS part. Fig. 1 compares the boundary schemes discussed above.

2.2 Slotted Frame

The two other principles, investigated in this paper, operate on a totally slotted pulse frame. This allows CS connections to be established within any slot without further restrictions. Only the maximum CS bandwidth should be controlled and both principles allow the usage of all time slots by PS, currently not being occupied by CS.

The "Idle Slot Concatenation" (ISC) principle treats all time slots for PS as a single PS channel. This operation is controlled by a CS/PS indicator at the beginning of each time slot, c.f. Fig. 2. The access to this channel is controlled by a token protocol as described above.

In contrast to these integration principles, the last one treats all PS slots as individual, parallel PS channels, which are used by small data units, called minipackets. Each minipacket contains the full address information to be switched within the network. The access of PS stations becomes controlled by an empty indicator, whereby empty slots are used on demand. The special requirements of the embedded CS traffic leads to a higher round trip delay, allowing every station to remove a minipacket at its destination, to free the time slot, or to use the same time slot immediately for a new minipacket to be sent (Fig. 3). This principle has been analysed and described in [1] and [2] and confirmed with an implementation in the laboratory.
3 Performance Evaluation

3.1 Simulation Results for the Token Access Scheme

The performance of the various integration principles on a ring system has been studied by means of simulations. The influence of the frame clock is compared for both principles operated by the token access on the PS channel. For all results, presented in this paper, a 10 Mbps ring with 10 stations and with 50% CS traffic (i.e. 73 Erl) has been assumed. The next figures present the mean waiting time of a 1 Kbit message versus the totally offered PS rate for several frame durations. Fig. 4 represents the results of a movable boundary system without rearrangement. Here, the pulse frame contains only a few bit overhead and therefore, the maximum throughput can be reached even with very short frames of 125 μsec. The only overhead, depending on the integration protocol, is a 2 byte header to indicate the current position of the boundary.

The ISC principle, able to use all slots in any case, requires 2 bit (CS/PS, Empty/Busy) per time slot. The time slots have been dimensioned to carry one 64 kbps (B) channel. A 125 μsec frame duration requires 8 bit per time slot, whereas a 1 msec frame duration implies a time slot of 64 bit. Fig. 5 reflects the different waiting times, caused by the differences in the relative overhead. For these systems a frame duration of at least 500 μsec should be recommended.
Figure 4: Movable Boundary system (without CS rearrangement)

Figure 5: Idle Slot Concatenation system

Figure 6: Comparison of the integration principles
Traffic Assumption:

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<tr>
<th>Station typ</th>
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<tbody>
<tr>
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<tr>
<td>Filesaver</td>
<td>6</td>
</tr>
<tr>
<td>Gateway</td>
<td>0</td>
</tr>
<tr>
<td>Big Workstation</td>
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<tr>
<td>Small Workstation</td>
<td>1, 3, 5, 7, 8</td>
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<th>25 11 14 11 65 11 104 11 11 14 227</th>
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<tr>
<td>[ \Delta \gamma ]</td>
<td>-9 -13 -9 -13 26 -13 -13 -13 -13 -9</td>
</tr>
</tbody>
</table>

Figure 7: Relative PS traffic flow matrix

3.2 Simulation Results for the Empty Slot Access Scheme

For a minipacket system, a frame duration of at least 1 msec is necessary, resulting in time slots of 64 bit. We define a minipacket to be of 16 bit header and 48 bit userdata. But the property of the minipacket protocol to use only the path from source to destination, allows a multiple usage of a time slot per frame cycle; in contrast to this operation, the token protocols, where a message can only be removed by the sending station, leads to one complete round trip in any case. Assuming symmetrically distributed PS traffic, Fig. 6 demonstrates the outstanding good performance of the minipacket protocol. Applying the analytical throughput calculation [1], it can be shown, that every time slot carries in average 2 minipackets per cycle on a symmetrically loaded system.

3.3 Unbalanced Loaded Minipacket System

3.3.1 Traffic Flow Matrix

To apply the calculation of the maximum PS throughput to unbalanced loaded systems using minipackets, relative PS traffic values are introduced. Fig. 7 also gives an example with 10 stations of 5 different types with different traffic relations between each other. As an example every small workstation sends a relative PS traffic of 3 to the fileserver, whereas they receive 12 from the fileserver. To obtain the real PS traffic values, the systemwide offered PS traffic \( \lambda_{PS} \) is needed. The relative system's PS capacity depends only on the traffic relations, given by the relative traffic flow matrix. Denoting one element in this matrix by \( Y_{PSij} \), a PS capacity factor \( \alpha_i \) can be defined for every link \( i \) (between station \( i-1 \) and \( i; N = \text{number of stations in the ring} \)):

\[
\alpha_i = \frac{N-1}{\sum_{j=0}^{N-1} \sum_{m=0}^{m+N-1} Y_{PSij}} / \sum_{k=i}^{N-1} \sum_{m=0}^{m+N-1} Y_{PSmk}
\]

The maximum PS throughput is limited by the link with the highest PS (minipacket) load, i.e. the link with the smallest \( \alpha_i \) and can be calculated by

\[
\lambda_{PS} = \frac{\Lambda_{PS}}{r} \ast \min(\alpha_i), \quad i = 0, 1, ..., N - 1,
\]
with $\Delta PS$ being the number of time slots available for PS and $r$ being the number of minipackets per message (e.g. 22 for a 1 Kbit message, as presented here). The value of $\alpha = \min(\alpha_i)$ represents the number of minipackets a time slot carries per frame cycle in average. More details of this analysis can be found in [1].

For the example, given in Fig. 7, $\alpha$ results to 1.57. In Fig. 6, two additional curves are depicted where two unbalanced loaded systems with $\alpha = 2.01$ and $\alpha = 1.57$ are compared to the balanced loaded system ($\alpha = 2.0$). The results in Fig. 6 demonstrate the better performance of the minipacket protocol, even in these situations.

### 3.3.2 Behaviour of a Single Station

The average waiting times for an unbalanced loaded minipacket system (Fig. 6) may hide the real behaviour of a single station. Therefore, the waiting times of 4 typical stations are examined in more detail:

The load on one link depends on the traffic relations between all stations. In the traffic flow matrix the sum of a column represents the total (relative) traffic a station sends, the sum of a row the total traffic which is received by this single station. Depending on the balance of this relative PS traffic ($\Delta Y$), at some stations the system carries a higher load. Fig. 8 demonstrates this for the system described.

Fig. 9 finally presents the waiting times for the file server, the host and two small workstations as defined in Fig. 7. Both workstations have identically traffic values, but one (#7) is located directly behind the fileserver, which sends a huge amount of minipackets. The fileserver suffers increasing waiting times at high loads, but all other stations remain within
moderate limits. So, even in unfavourable load situations, the minipacket protocol allows an acceptable operation of the system and a fair distribution of the available bandwidth between all stations.

4 Conclusion

New communication systems require the integration of a broad range of services. In the near future, systems should be able to support the two 'classic' switching principles: circuit switching and packet switching to allow simple interfacing to existing terminals and systems. The first approaches in the field of the local / metropolitan communication allow a flexible sharing of the bandwidth, and the presented minipacket protocol combines very good performance with high flexibility and keeps the way open for a migration towards an increasing amount of packetized services.

5 Acknowledgement

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References


