INVESTIGATIONS ON TRAFFIC CHARACTERISTICS
AND NETWORK BEHAVIOUR IN DATEX-P

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ABSTRACT

In this paper the main results of statistical investigations and measurements of the West German packet switching system DATEX-P are presented. These measurements were made from 1983 to early 1985. Traffic distributions in DATEX-P are shown and subscriber groups HTS, MTS and LTS are introduced.

The paper evaluates the influence of traffic patterns on network performance and deals with the impact of the measurements on network performance and node engineering. The investigations are interpreted and a quality of service indicator, the Performance Factor (PF) is proposed.

1. INTRODUCTION

In August 1980 the Deutsche Bundespost's Packet Switched Digital Network (PSDN) DATEX-P began commercial service with 17 switches at 17 node sites. DATEX-P offers a broad range of service protocols and speeds for packet mode and non-packet mode terminals. For non-packet mode services the PAD (Packet Assemble and Disassemble) function is provided by the network.

1.1 Current Network Status

As of December 1984 7 812 ports were in service. The December 1983 count of ports in service was 4 179. This is an annual growth rate of 87% which correlates well with the forecast data. As this data show a continuous high rate of growth the Deutsche Bundespost expects about 30 000 connections by the end of 1987.

At the end of 1984 the network comprised of 35 nodes and two network control centres (NCC). Nodes are interconnected by trunks at speeds of 64 kbps.

Two switching centres in Düsseldorf and Frankfurt process international traffic. 29 international trunks (9.6 Kbps) according to CCITT Recommendation X.75 connect DATEX-P directly to foreign packet switched data networks.

The first international trunk at a speed of 64 Kbps to Switzerland will be in service by the end of 1985.

The service mix remained static from 1983 to 1984:

<table>
<thead>
<tr>
<th>Portion of total ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>X.25</td>
</tr>
<tr>
<td>December 83</td>
</tr>
<tr>
<td>December 84</td>
</tr>
</tbody>
</table>

Table 1. Service Mix

The main service protocol is by far X.25. DATEX-P offers several speeds for X.25 from 2.4 kbps to 48 kbps. The speed mix remained static from 1983 to 1984 as:

<table>
<thead>
<tr>
<th>Speed/kbps</th>
<th>2.4</th>
<th>4.8</th>
<th>9.6</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 83</td>
<td>30%</td>
<td>28.0%</td>
<td>41%</td>
<td>1.0%</td>
</tr>
<tr>
<td>December 84</td>
<td>31%</td>
<td>28.5%</td>
<td>40%</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Table 2. Speed Mix

1.2 Reasons for Traffic Measurements

The investigations of traffic characteristics and studies on user behaviour can be divided in two main areas of interest:

a) Improving the cost efficiency of installed or planned system components,

b) Offering the best possible quality of service for the user.

The resulting traffic data can be applied to a variety of activities, such as planning, tariff studies, cost optimization and detection of service degradations.

The objective of all traffic investigations is to maximize the utilization of all resources within the constraints of grade of service, in general called node engineering.

2 STRUCTURE OF A DATEX-P NODE

In the following chapters the main concern will be to investigate how traffic flow and distribution influence LP and node engineering. For a basic understanding the physical model used throughout this paper is illustrated in Fig.1.
There are three significant resource components of the node for engineering purposes. These are:

a) High Speed Line Processor (HSLP) with
   * processing power - to handle packet processing
   * local memory - to store program code, service data, packet messages and process control blocks
   * physical fanout - to accommodate subscriber lines
b) Trunk Processor (TP) with
   * trunk bandwidth - to handle traffic to and from other nodes
c) Common System with
   * common memory - to store service data, control and message blocks
   * common bus bandwidth - to ensure operation of the multi-processor system
   * control processor (CP) processing power - to handle call set-ups, clears and administrative functions
   * processor fanout - to accommodate desired processor types

The most important component of node engineering is line processor (LP) engineering. This importance is due to the relatively large proportion of total nodal resources which is attributed to line processing and to the frequency with which changes are made that affect the LP.

3 TRAFFIC MEASUREMENTS

3.1 General Aspects

The traffic measurements are based on two sources. The Data Collection Centre (DCC) collects DATEX-P statistics of the main network components at 15 minute intervals. Hence this paper uses this time interval as a basic unit for statistical measurements.

The 15 minute interval of a day during which the busiest traffic behaviour occurs is defined as the busy quarter hour (BQH). In this paper the BQH is restricted to a nodal environment without operational hardware and software problems.

The second source for traffic measurements are the accounting records. The record e.g. keeps track of call set-up/clear and duration times and is therefore useful for user behaviour investigations.

3.2 General Traffic Measurements

3.2.1 Network Traffic Trends

The subject of growth in a PSDN can be viewed from two perspectives: number of ports and the traffic volume resulting from the connected ports. These two parameters are important, since they directly affect the revenue stream that can be expected from the number of subscribers. As one can see in Fig.2, a doubling of the number of subscribers may not result in an automatic doubling of equipment. The exact cost impact will depend solely on the effect on the network traffic characteristics. If the traffic per port drops, then the cost of provisioning drops since less common equipment is needed.

Fig.2 is a good example, how sensitive the subscribers react to economical influences. Traffic per port dropped significantly over the May-June time frame. The per port erosion of traffic cannot be explained by changes in the mix of the ports since the proportion of X.25 ports has not changed. A good explanation might be that the customers reacted with their applications to the announcement of a change (higher rates) in the tariff structure. The second drop in traffic reflects the industrial strike period in Summer 1984. A recovery to the normal trend can be seen. The December drop is due to Christmas holidays, as the recovery in Jan/Feb 1985 showed.

3.2.2 Distribution of Traffic Volume

One of the most cost intensive components of a digital network is the line access system. DATEX-P uses currently static multiplexers to reduce the backhaul costs. Concentrators with a more economical use of the bandwidth are far more cost effective but require from the network engineer detailed knowledge of the geographical distribution and traffic volume of the connected data terminals.

Hence a long term investigation was made to determine, if and how DATEX-P could use concentrators without losing an adequate quality of service.
Fig. 3 shows the distribution of the traffic volume found.

Fig. 3 DISTRIBUTION OF TRAFFIC VOLUME

In DATEX-P segments (1 segment = max. 64 octets) are used as accounting units. Subscriber categories could be based on the amount of segments they produced. Thus the subscribers were classified into three groups:

<table>
<thead>
<tr>
<th>Group</th>
<th>Volume/day</th>
<th>Subscribers '83 '84</th>
<th>Traffic '83 '84</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTS</td>
<td>&lt; 5 KSegm.</td>
<td>80% 80%</td>
<td>13% 11%</td>
</tr>
<tr>
<td>MTS</td>
<td>5-50KSegm.</td>
<td>17% 17%</td>
<td>37% 40%</td>
</tr>
<tr>
<td>HTS</td>
<td>&gt; 50KSegm.</td>
<td>3% 3%</td>
<td>50% 49%</td>
</tr>
</tbody>
</table>

Table 3 Subscriber Traffic Groups

The HTS group consists of about one third subscribers who use SVCs and two third use PVCs. The SVCs produce less than 30% of the HTS traffic. This reflects the situation of the remainder of the network, where the SVCs produce just 30% of the whole traffic. It should be noted that the logical channel distribution of LTS and MTS is 67% SVCs to 33% PVCs.

Based on the geographical distribution of the data terminals it could be determined that about 60% of the LTS group could economically be connected to concentrators. The movement between the 3 traffic groups stayed far below 10% during a period of 1 year. Hence the costly risk of having to remove traffic intensive MTS or HTS from the concentrator is very low.

3.3 Traffic Profiles
3.3.1 Network Traffic Profiles

The hourly traffic variation is based on LP statistics for the number of frames received and sent. The relationship of LP frames per second to data packets per second (DPPS) is approximately constant. As long as the relationship between frames and DPPS is static, the use of LP frames for analysis purposes is acceptable.

The values on Fig. 4 are based on the total sum of all network LP frames for one quarter hour for each hour from 05.00 to 21.00 hours. The totals of each quarter hour for four days in 1984 (Apr 26, Jun 12, Sep 11 and Dec 12) are then averaged for Fig. 4.

The chart shows a fast increase in traffic during the morning with slower drop off in the afternoon. There is a noticeable decrease at noon. The business day will be defined as from 07.30 to 18.00 so that postponable maintenance activities should not occur within this interval. One important observation from this chart is that the time of day tariffs (day tariff from 08.00 - 18.00) do not have a major impact on the traffic distribution. In fact the traffic after 18.00 to 21.00 is mainly due to international traffic.

The present night tariff reduction of 45% of the peak tariff rate seems not to be an incentive to shift larger proportions of the traffic to night hours.

The daily traffic variation is illustrated in Fig. 5. The chart is based on a series of measurements during 1984. The results are con-
3.3.2 Node Traffic Profiles

Though most of the hourly traffic profiles of the single nodes is quite similar to the traffic profile of the network, there were some significant deviations found in the profile of some single nodes.

Fig. 6 shows an example of a node with a different hourly traffic profile. Further investigations showed that the node's behaviour was due to one subscriber whose application (international traffic) had an impact of the traffic profile of this node (notice the shifted BQH and traffic distribution until midnight).

Fig. 6 NODE TRAFFIC PROFILE

With the knowledge of node traffic profiles maintenance activities can be influenced so that postponable work can be pushed to off-hours.

3.3.3 LP Traffic Profiles

Since October 1984 DATEX-P is using a set of integrated statistic programs for operational and planning purposes. The Operational Measurements and Analysis Tool gives the network operator and engineer an opportunity to analyse the statistics of the most important network components.

The analyst is able to predefine thresholds and automatically run benchmark tests to flag only those network components that show an unexpected or abnormal behaviour. As the LP's behaviour is of major concern for engineering a node, Fig. 7 and 8 show the plot of the hourly traffic profile on LPs.

The LP contains local memory, some of which is set aside for the local work queue to transfer messages between processes to and from the common system. To check the node condition the number of free memory blocks is sampled approximately every 4 seconds. A running total of these samples is reported to the node every minute.

The results of this procedure are compared to the current throughput rate to find a correlation of the statistics.

Throughput and utilization increase and decrease at the same time in a normal manner. The memory drops when the throughput increases because of the allocation of message blocks from the initial memory free queue.

The key is to compare simultaneously the memory use with the throughput rate and the processor utilization to indicate the node condition. If the processor utilization is high while the throughput is low, a trouble situation is indicated.

Fig. 7 illustrates the plot of an abnormal behaviour. Throughput and utilization increase and decrease at the same time, however the utilization is off-set from the throughput. Normally the curves run close together in parallel.

In this case there is a constant off-set between the LP utilization and the packet processing curve. The scales of the U- and P-curve are chosen in such a way that the two curves run close together, when the LP behaves normally.

The off-set means a high background utilization that can be caused by an unstable line or faulty modem, or by having the LP configured incorrectly for the type of service it is serving (e.g. mismatched speeds).

Another example of how valuable LP plots are for the network engineer and operator is shown in Fig. 8. In the abnormal range the processor experiences little or no throughput but has a high background utilization.

This may indicate a processor problem, a test condition or a bad line/modem. The significant drop in the utilization curve indicates that the operation group detected the reason for the abnormal behaviour and solved the problem so that the utilization curve behaves as expected.
4 LP TRAFFIC ENGINEERING

4.1 Quality of Service Indicator (PF)

Fig. 7 and 8 illustrate the problems resulting from inefficient line operation. In a normal operating environment it is not desirable to detect inefficient LP behaviour through this means; consequently the concept of Performance Factor (PF) is introduced.

PF is simply the ratio of LP frame throughput to the LP processor utilization. All things being equal, the LP should be able to process a certain number of frames for each increment in LP utilization. The absolute number of frames processed per % increment is not important. What is important is to flag those few LPs which are not being used to service frames but other interrupts (protocol errors, modem status changes etc.).

By removing the non-productive interrupts, the effective throughput of the network can be improved.

4.2 Calculation of LP Utilization

Node performance optimization requires the careful engineering of the Line Processor. The engineering of a node may be addressed in two different ways. The first approach begins with a standard node configuration of LPs with service protocols. This approach is concerned with how many access lines of different traffic characteristics can be terminated. The second approach begins with a given number of access lines of different traffic characteristics to be terminated on the node or site. The main concern of the second approach is how many LPs and therefore how many nodes of what configuration are required.

The major consideration for the LP is CPU utilization. A target utilization is chosen and engineered towards. There are 3 phases in the engineering process:

i) Prediction: Estimation of traffic for new lines;

ii) Monitoring: The predicted resource utilization is compared to actual measurements on the operating node;

iii) Adjustment: Addition or removing of lines to meet the target values of LP utilization.

The currently recommended target CPU utilization is 60% for the BQH. Values of about 80% indicate an overload situation that is defined as the utilization level at which customers experience degraded service such that customer complaints will occur. To predict the usage of LPs the network engineer has to calculate the total LP utilization TUT. TUT is defined as the sum of the utilization fractions UTILj due to each of the lines assigned to the LP and the utilization fractions CUTj due to call setup and call clearing.

As a result of a series of measurements in the live network and theoretical investigations some formulas were defined to be used before the line assignment process.

In equation form the total utilization TUTj of LPj is:

$$TUTj = UTILj + CUTj \quad (E2.1)$$

The value of UTILj can be calculated once the following has been found:

* throughput of each line, Ri;

* packet processing time for each line type, Ti;

* LP capacity for each line type, Ci.

The LP utilization due to line i is given by:

$$UTILi = \frac{100}{C_i} \times Ri \quad (E2.2)$$

Hence

$$UTILj = \sum UTILi = \sum \frac{100}{C_i} \times Ri \quad (E2.3)$$

As an example the value of UTILj for X.25/HDLC lines can be calculated as follows:

$$R = S \times \frac{Uin/(8\times100\times(L+H1))}{DPPS} \quad (E2.4)$$

where:

* S = line speed in bps

* Uin = percent line utilization into the LP due to data packets only

* L = average packet length in octets

* H1 = overhead bytes (8 bits) for data packet, packet RR and frame RRs.

Averaged values of DATEX-P: L = 48

$$H1 = 30$$

The H1 value assumes low % piggybacking at the frame and packet level that was found as the most dominating behaviour.

The total line processor throughput capacity, at 100% utilization (saturated) is:

$$C = \frac{1000}{T DPPS} \quad (E2.5)$$
Where: \( (1 \text{ DPPS in} + 1 \text{ DPPS out}) = 2 \text{ DPPS}; \)
\[ T = \text{total packet processing time in ms} \]
as determined for each service.

The packet processing time \( T \) for X.25/HDLC lines is given as:
\[ T = q + r \times L \quad (E2.6) \]
where: \( q \) = overhead processing time in ms
\( r \) = length-dependent packet processing time in ms per octet
\( L \) = average packet length in octets

\( E2.6 \) was found to be accurate to within 6% for packet lengths of 32 to 128 octets. For the current software release the following values were measured:
\( q = 15 \text{ ms} \) and \( r = 0.035 \text{ ms/octet} \)

Table 4 shows the currently used values for the number of X.25/HDLC lines at different line utilizations for an estimated LP utilization of 10%.

<table>
<thead>
<tr>
<th>Line Speed/ bps</th>
<th>Line Utilization</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2400</td>
<td>L = 48</td>
<td>15.6</td>
<td>27.7</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>L = 128</td>
<td>7.8</td>
<td>13.5</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>L = 128</td>
<td>3.9</td>
<td>6.8</td>
<td>1.9</td>
</tr>
<tr>
<td>4800</td>
<td>L = 48</td>
<td>15.6</td>
<td>27.7</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>L = 128</td>
<td>7.8</td>
<td>13.5</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>L = 128</td>
<td>3.9</td>
<td>6.8</td>
<td>1.9</td>
</tr>
<tr>
<td>9600</td>
<td>L = 48</td>
<td>15.6</td>
<td>27.7</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>L = 128</td>
<td>7.8</td>
<td>13.5</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td>L = 128</td>
<td>3.9</td>
<td>6.8</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Table 4 Estimated nr. of lines for 10% LP UTIL

The fraction of LP utilization due to call set up and call clear operations in the BQH is calculated with:
\[ \text{CUTj} = \frac{\text{Ncc}}{\text{Kcc}} \times 100\% \quad (E2.7) \]

Where: \( \text{Ncc} = \text{avg. nr. of combined call setup} \)
and clearings per second
\( \text{Kcc} = \text{Ncc at LP saturation} = 5.6 \) as measured in lab environment for X.25 through one LP only.

A series of snapshots of the user behaviour showed and traffic analysis confirmed that presently the fraction of processor utilization \( \text{CUTj} \) due to call activities is negligible in DATEX-P.

The average call duration time for the SVCs is 6033 seconds on an average business day. The bandwidth of call durations is from less than 80 seconds up to more than 19000 seconds per call. Unless the user behaviour changes significantly the utilization is not a function of call activities.

When DATEX-P began commercial service the user behaviour was unknown and thus the prediction of the traffic amount per line had to be conservative to avoid overload situations just at the beginning.

After a period of intensive studies on the network and subscriber behaviour in 1983 and 1984 it could be summarized that the initial predictions of the initial phase were too high. The net result of the original guide-

lines can be illustrated by Fig.9 which shows the current LP utilization.

From a resource utilization perspective the ideal shape means the optimal use of the common equipment without degrading the quality of service. Current efforts is to engineer the processors to carry more load thus shifting the LP utilization upward.

5 TRAFFIC PROFILES OF USER GROUPS

5.1 General Aspects

In the assignment process it is important for the network engineer to know as much as possible about the available statistics of the subscriber lines and the node that will have to serve the lines.

To provide the customer with the best quality of service the current node behaviour, especially the LP behaviour should be known. The hourly LP traffic profile should be used to define the LP's BQH and distribution of the traffic amount.

If the user behaviour during the business day is also known the two traffic patterns should be normalized to a common base and then compared. Usually the network provider doesn't know too much about new lines and their future traffic behaviour. In fact even the subscriber's estimation is not very accurate.

To avoid overload situations and to use the provided LP bandwidth efficiently the single lines assigned to the LP should consist of a mixture of lines with different user behaviour.

In the worst case all lines of the same LP produce the traffic only at the same time of day during a short period of time. Though the LP is idle almost all the time, the connected subscribers could experience a degradation of quality of service, if their traffic volume is high enough.

The theoretically ideal model is to combine lines with equally distributed BQHs. Thus the LP's load is distributed over the whole business day.

To approach the ideal model investigations in DATEX-P were made to determine traffic profiles of special user groups with different business oriented traffic distributions.
Once typical shapes for special user groups are found, the prediction of the user's behaviour and estimation of the traffic volume of a single line is more accurate than to take an average of all existing subscriber lines.

5.2 Business Oriented Traffic Profiles

The investigation is based on the 300 busiest subscriber lines in DATEX-P. At the end of 1984 these lines consisted of 74% HTS and 26% MTS producing about 55% of the whole traffic volume. Most of the lines (99%) used a speed of 9.6 Kbps.

The initial research started with three user groups:

* Banking business,
* insurance business and
* department store business (including mail-order firm applications).

Fig.10 TRAFFIC PROFILE/BANKING BUSINESS

These three business groups represented a total traffic percentage of 19% and included 10% of the 300 busiest lines.

Fig.11 TRAFFIC PROFILE/INSURANCE BUSINESS

For every business oriented group a FORTRAN program plotted the traffic profile of an average business day. Then 5 samples of single lines, that didn't belong to the 300 busiest lines, but belonged to the investigated user group, were plotted and the shapes of the traffic profile were then compared.

In most of the cases a good correlation could be determined. The main deviations could be seen for department store business. Closer analysis revealed that this was due to the impact of not having separated Host to Terminal from Terminal to Host communications.

Fig.12 TRAFFIC PROFILE/DEPARTMENT STORE BUSINESS

Fig.10 to Fig.12 illustrate clearly the different user behaviour of the business oriented groups. While the banking and insurance business profiles reflect the behaviour of the whole group as well as the behaviour of a single line, the traffic profile in Fig.12 is only accurate for Terminal to Host traffic in the time frame from 08.00 to 19.00.

The night traffic from 04.00 to 06.00 is due to the summarized Host to Terminal communication. The business day traffic is mainly based on interactive dialogue sessions with only short responses from the Host. The night traffic is due to file transfers from Host to Terminal.

Further investigations will have to determine more typical user groups and their traffic profile based on separated Host to Terminal and Terminal to Host communications.

6 CONCLUSIONS AND FURTHER RESEARCH

The paper has analyzed the distribution of the traffic volume in DATEX-P and introduced three main subscriber groups that are classified by the produced traffic amount. The impact of traffic distribution and user behaviour on network and node engineering has been discussed and the influence on the quality of service indicator, the Performance Factor (PF) has been proposed. Further researches will be initiated to cover the remaining business oriented groups to provide the network engineers as well as the marketing groups with the findings. With the added information the network utilization, both current and planned, can be optimized.