# A COMPATIBLE MULTIPLEXING TECHNIQUE FOR ANISOCHRONOUS AND ISOCHRONOUS DIGITAL DATA TRAFFIC

Nobuhiko Shimasaki and Tohru Kohashi
Nippon Electric Company, Ltd.
Tokyo 108, Japan

Kohei Habara
the Research and Development Bureau
Nippon Telegraph and Telephone Public Corporation
Musashino 180, Japan

Yasunobu Suzuki
Musashino Electrical Communication Laboratory
Nippon Telegraph and Telephone Public Corporation
Musashino 180, Japan

## Summary

This paper reports the result of a study on a multiplexing scheme for digital data transmission and switching which can handle both anisochronous and isochronous data traffic of various mix, mainly in one 1,544 kb/s digital channel.

The study aims to determine a unified scheme which is economical and flexible for inter-city heavy traffic data links in the Japanese domestic digital data network, to accommodate a wide range of data speeds.

The paper describes various multiplexing schemes and analyzes their features in terms of frame structure, synchronization time, error correction capability, compatibility with signaling, hardware complexity etc.

A bit-interleaved multiplexing scheme is chosen as suitable and will be applied in a laboratory model of digital data switching system which is under construction.

## 1. Introduction

The CCITT Joint Working Party NRD (1968-72) made studies of a digital data network, in which asynchronous data networks are treated separately. The result of a study on a synchronous data network multiplexing scheme appears as CCITT Recommendation X.50[1]. The recommendation was supported as a basis of international interworking of synchronous data networks.

It seems worthwhile, however, to study, as the third approach, a unified digital data network where a wide range of various anisochronous and isochronous data terminals, including digital facsimile (FAX) terminals, are served together.

This approach can be considered as well-matched to the Japanese situation, because it is hard to predict the future trends of various domestic data traffic demands in Japan. The majority of currently operating data terminals in Japan are classified as anisochronous terminals, including telex terminals. The application field for digital leased data transmission line service could grow rather rapidly. The growth of digital facsimile service is also expected, based upon the fact that the Japanese have been utilizing many Chinese characters, as well as their own characters in communication. On-line computers equipped with packet-interleaved communication function[2] could become important data traffic sources/sinks in the future.

This paper is concerned with the multiplexing schemes of such a unified network reflecting the third approach.

## 2. System Requirements

### 2.1 Network Service Requirements

The following items make up a part of the service requirements of the Japanese public digital data network, which is closely relevant to the multiplexing structure of the network.

(1) Terminal speed distribution: The network covers the wide range of terminal speeds between $50^{b/s}$ and $96^{kb/s}$, as listed in column (a) of Table 1. The future speed distribution in Japan would be close to the average of that of western European countries, estimated for the 1980's[3]. Anisochronous data traffic is estimated as more than half of the total traffic. It is also predicted that the number of digital high-speed FAX terminals would be only several percent of the total and 48 kb/s isochronous traffic would not be very significant.

(2) Geographical data traffic terminal distribution: The heavy concentration of population and business firms in rather narrow urban and suburban areas along the Tokyo-Nagoya-Osaka megalopolis zone will be reflected in the geographical data distribution in Japan. A forecast based upon market surveys indicates that about 60, 30, 10% of the future Japanese data terminal would be located in urban, suburban and rather rural areas, respectively.

(3) Implication of digital leased-line service in the network: Economical mixture of the digital leased-line service with switched service in a digital data network, is to be taken into account.

### 2.2 Multiplexing Scheme Technical Boundary Conditions

The following items make up a set of technical boundary conditions.

(1) Principal digital transmission channel: 1,544 kb/s digital transmission channel is available for the 24-channel PCM telephone system in a short-haul exchange area and for the long-haul transmission PCM-FDM channel[4].

(2) PCM hybrid data transmission terminal equipment: A PCM hybrid data transmission system is available as possible light-loaded digital data transmission sub-channels at 64 kb/s (effectively 56 kb/s)[5].

(3) Subscriber line base-band digital data transmission: The base-band transmission system is applied to subscriber lines. Adoption of a three-level subscriber-line signaling system, corresponding to the base-band transmission system, is also considered[6].

## 3. Design Considerations

### 3.1 Technical Requirements

Technical requirements to be pursued in the actual design choice are as follows:

(1) Bit error rates are to be improved by the order of one tenth or one hundredth, in comparison with the figure of conventional telephone switched network, e.g. $10^{-5}$.

(2) Distortion of an anisochronous data stream, in a multiplex channel chain between originating and terminating multiplex equipment, is to be less than 10%, in order to satisfy the specification concerning end-to-end data pulse distortion.

(3) Time division switching equipment[7] is to be simplified.

(4) Shorter frame length of the multiplexing structure is to be pursued from the viewpoint of short synchronization recovery time[8].

### 3.2 Fundamental Factors

There are many fundamental multiplexing structure factors to be taken into consideration. Among them are the following:

(1) Fundamental digital multiplexed channel bit rate: Two possible fundamental bit rates in Japan, 64 kb/s and 1,544 kb/s, seem to have their own application fields. 64 kb/s and its multiple seem to be applied mostly in rural and suburban areas where low density data traffic flow could not fill up a 1,544 kb/s multiplexed channel to a reasonable level. 1,544 kb/s seems appropriate for inter-city heavy traffic links. The following favorable aspects could stand:

a) Improvement of traffic handling capacity, due to possible application of heterogeneous traffic switching[9], is expected.

b) Higher flexibility than that of 64 kb/s x n channels is generally expected, when a part of the channel is pre-assigned to leased-line services and the remainder is utilized for switched service.

c) 1,544 kb/s time division switching equipment realizes generally higher traffic handling capacity.

d) Very high-speed leased-line service, such as 24 kb/s or 384 kb/s service, could be offered rather easily.

e) Several logical subnetworks, equipped with lower-bit-rate digital transmission channel and different network topology, could share a physical 1,544 kb/s digital transmission channel network through possible utilization of fixed time sub-channel pre-assignment in some switching points.

(2) Digital signal coding: Possible signal processing approaches, combined with binary digital multiplexing, can be considered from the following view points.

(i) Sampling versus transition encoding: Transition encoding[12] is a very attractive method for long-haul anisochronous data traffic. But it is eliminated from further consideration here because the complexity of corresponding per-subscriber-line hardware seems rather high.

(ii) Synchronization of low speed data traffic into the system: It seems impractical to enforce the adoption of burst isochronous mode by many low-speed data terminal equipments merely in order that they can then join a public digital data network.

(iii) Envelope or character processing at multiplexing point: Adoption of the envelope processing approach to some isochronous data traffic is relevant to the following multiplexing format choice. It is also to be estimated from the viewpoint of matching subscriber signaling functions.

The adoption of character processing, such as the packing of 8 consecutive samples into an 8-bit word is eliminated from further consideration, because of complexity of the subscriber circuit (DCE-S) due to the necessity for buffer memory facilities and digit detector/generator.

(3) Multiplexing format: There are three possible multiplexing formats, i.e. (a) bit-interleaved, (b) (6+2) bit-envelope interleaved and (c) (8+2) bit-envelope interleaved.

(a) Bit-interleaved approach provides the smallest format length and a short frame length, which is favorable to make an economical time division switching system including synchronization equipment and message path equipment. It is also very flexible for multiplexing system modification. In order to identify data/signaling messages, however, this approach requires a special measure, such as three-level subscriber line signaling[6] combined with separate common channel signaling in multiplexed channel links.

(b) (6+2) bit-envelope[1] is compatible with PCM-coded 8 bit digital voice message. However, the mismatching with a set of conventional 8 bit character plus F & S bits, in this approach, requires packing of three consecutive 8-bit characters into four 8-bit time slots.

(c) (8+2) bit-envelope, which was proposed to CCITT by the U.K.P.O.[10], simultaneously satisfies all the conditions: Compatibility with smooth character sending and receiving at data terminal equipment, easy separation of signaling information in the link between data terminal and switching center, and all unified two-level transmission from end to end. There seems to be some difficulty from the viewpoint of compatibility with PCM-coded digital voice message.

(4) Number of samples per data digit:

(i) Low speed terminal: Some measures are to be taken in order to realize the overall network bit error rate of $10^{-7}$. Therefore, in tandem connection of several switching stages, bit error rate design targets of $10^{-6}$ and $10^{-7}$, are considered for short-haul PCM-24 telephone system and long-haul PCM system, respectively. Multiple-point sampling, combined with majority logic type common digit detection, seems to be the easiest measure to realize economical hardware for low-speed data circuit terminating equipment (DCE) and corresponding subscriber circuit (DCE-S), because the average pulse occupancy of a multiplexed channel carrying low-speed data traffic is relatively low. This consideration holds for both isochronous and anisochronous data terminals.

Besides the above, the application of multi-point sampling to an anisochronous data terminal is based upon other intrinsic reasons.

(ii) High speed terminal: The improved overall end-to-end bit error rate still seems realizable, because high speed data terminals of 48 kb/s etc. are sufficiently expensive to be able to ignore the price increment due to high-class error control facilities for error detection, correction and/or end-to-end retransmission. A digital FAX terminal does not require error control functions, such as the above, because a network bit error rate of less than $10^{-4}$ is sufficient in practice. Considering the above situation and the rather high pulse occupancy of a multiplexed channel, single-point sampling seems applicable to a high-speed data stream.

(iii) Overall considerations: Thus, the combination of multiple-point sampling applied to both anisochronous and isochronous low speed terminals and one-point sampling to high-speed terminals can simplify the series of digital carrier bearer rate without sacrificing required qualities on overall message error rates The realization of a better undetected error rate of $10^{-9} \sim 10^{-11}$ could be expected, when the acknowledgement/retransmission procedure etc. are applied to the links between switching points of packet-switched mode[11]. However, the end-to-end error rate between terminals is dominated by the quality of the links between terminal and switching point.

## 4. Classification of Various Possible Multiplexing Schemes

### 4.1 Classification

Two facets, i.e. (1) selection of switching modes corresponding to different application fields, and (2) application of various combinations of fundamental techniques for multiplexing, seem most suitable as the basis of classification.

Figure 1 and Table 2 indicate the classification model from the viewpoint of facets (1) and (2) above, respectively.

Figure 1 illustrates a model of the combination of various switching and concentration/distribution modes, which are applied to urban/suburban/rural regions, or, high/middle/low traffic density zones, on the basis of optimum allocation of facilities. The basic functions of the local subnetwork are, of course, (1) the concentration of low level traffic flow of individual terminals, into 1,544 kb/s (or 64 kb/s) multiplexed digital channel, and (2) traffic switching at the data switching exchange (DSE) stage. Remote allocation of 1st multiplexer and/or 2nd multiplexer/concentrator, corresponding to the traffic (or terminal) density of the application fields, seems essential for the realization of a optimum local network structure.

The considered local subnetwork, as illustrated in Figure 1 with the list of functional units, has three typical hierarchical approaches, i.e.: (1) Application of 1st MPX and 2nd MPX combined with remote concentrator, to a rural area, (2) Application of 2nd MPX combined with remote concentrator to suburban and urban area, and (3) Application of central concentrator to urban area.

The assumed DSE has the function of circuit-switching utilizing TDSW, as well as of packet-switching utilizing CCE.

It is observed as natural that the DSE of the lowest switching stage would be mostly located corresponding to DC of the public telephone network, as illustrated in Fig. 1, because the scale of digital data service demand is small in comparison with that of conventional telephone service demand. Consequently, the location of 2nd MPX/RLC would be corresponding to that of telephone TC in most cases.

The model illustrated in Figure 1, is placed as a basis of the study described below in this paper.

Table 2 shows the typical multiplexing schemes of 1,544 kb/s channel. Three types considered based upon multiplexing format, are: Bit-Interleaved (Class A), Bit/Envelope Hybrid-Interleaved (Class B) and Envelope Interleaved (Class C). Class B is a kind of hybrid type of fundamental two classes, A and C. Two typical subclasses of each class are chosen from the viewpoint of bearer rate series of multiplexed channel, their correspondence to terminal speed being as indicated in Table 2.

4.1.1 Bit-Interleaved. Two classes, A1 and A2, correspond to typical fundamental sampling rates, 2 kHz and 2.4 kHz, respectively.

(1) Class A1 (See Table 1): Multiple-pulse sampling of 2 and 12 kHz applied to low-speed anisochronous data terminal, as well as to an isochronous data terminal with lower speed than 48 kb/s, causes an improvement of bit error rate in the network, which has generally the trading-off relation with the decrease of the degree of multiplexing. Another feature, in comparison with Class C especially, is the possible lower cost of DCE and per-subscriber-line circuit unit of multiplexer.

(2) Class A2: 2.4 kHz sampling is applied to terminals using a speed not greater than 2.4 kb/s, assuming middle-speed terminals, using a speed not less than 600 b/s, are all isochronous.

This approach provides a solution having more emphasis on the degree of multiplexing, rather than on the improvement of error rate due to multiple sampling, because synchronous transmission utilizing one-point sampling is applied to middle-speed data terminals which require generally higher channel occupancy than that of low-speed terminals, if the above assumption stands.

There is room for choice about alternative sampling rate series, such as 1 kHz series, in order to optimize the scheme, if the conditions of terminal speed distribution and the border line speed between isochronous and anisochronous mode could be fixed more precisely.

4.1.2 Envelope-Interleaved. Two classes, C1 and C2, correspond to (6+2) bit envelope [1] and (8 + 2) bit envelope[10], respectively. The former has better compatibility to 8 bit x 8 kHz (64 kb/s) channel of PCM telephone transmission system. The latter utilizes bearer rates of overspeed and, therefore, a kind of pulse stuffing is associated with it. Both classes have the same length of multiplexing frame, 10 milliseconds.

Envelope processing including sample-pulse bunching at multiplexing point is applied to data traffic at all kinds of data speed.

4.1.3 Bit/Envelope Hybrid-Interleaved. This is a hybrid of classes A and C, where bit interleaving combined with multiple sampling is applied to low-speed anisochronous data traffic. However, on the other hand, envelope-interleaving is applied to middle-to-high speed isochronous data traffic. The difference between classes B1 and B2 corresponds to (6+2) bit envelope and (8+2) bit envelope.

Thus, low-speed anisochronous data traffic is free from envelope processing, including sample pulse bunching, and 2 kHz and 1.8 kHz equi-interval sampling is applied to Classes B1 and B2, respectively.

The situation pertaining to isochronous data handling by envelope-interleaving is similar to the cases of pure envelope-interleaved classes described in §4.1.2.

### 4.2 Comparison

Comparisons from the viewpoint of channel capacity, cost etc. are described below, on the basis of the local subnetwork configuration (Figure 1) and typical 1,544 kb/s multiplexing schemes (Table 2).

The following homogeneous terminal speed distribution and average traffic per terminal are postulated in the numerical calculation of this section:

| Class No. i | Terminal speed class range | Ratio of terminal number: Ti | Average traffic per terminal: $\alpha_i$ |
|---|---|---|---|
| 1 | 50 ~ 200 b/s | 50 % | 0.2 erl |
| 2 | 2400 b/s | 30 % | 0.2 erl |
| 3 | 9600 b/s | 16 % | 0.05 erl |
| 4 | 48 kb/s, 96 kb/s | 4 % | 0.15 erl |

where the average traffic per 96 kb/s FAX terminal is translated on a 48 kb/s basis. This assumption corresponds to the statement of §2.1 (1).

4.2.1 Channel Capacity. Two kinds of channel capacity, or degree of multiplexing, are listed in Table 2, based upon the various assumptions given previously. The left column under the channel capacity heading shows figures in the case of application of traffic concentration at the 2nd MPX point. On the other hand, figures on the right column indicate the non-remote traffic concentration case.

Channel capacities C are calculated by the following formula with remote traffic concentration:

$$C = \frac{(192x8 - S.F)^{kb/s.}}{\sum_{i=1}^{4} Bi \cdot Ti \cdot \alpha_i} \quad (1)$$

without remote traffic concentration:

$$C = \frac{(192x8 - S \cdot F)^{kb/s}}{\sum_{i=1}^{4} Bi \cdot Ti} \quad (2)$$

In (1) and (2) above, i, Ti and $\alpha$ i are described already in §4.2, and Bi: bearer rate assigned to class i (kb/s); F: frame frequency (kHz) as indicated in the frame format column of Table 2, inversely to frame length; S: number of common channel signaling bit per frame, being assumed as 48, 40, 240, 320, 0 and 0 corresponding to schemes A1~A2 of Table 2. $\eta$ = 70 % is the assumed average traffic efficiency of a multiplexed channel. Application of remote traffic concentration to the schemes C's seems less practical, as indicated by parentheses in Table 2, because the complexity of hardware implementation seems large for envelope processing combined with variable time channel assignments around DCE-S.

Scheme A2 with remote concentration shows, thus, the highest channel capacity in this table. However, possible anisochronous 1200 b/s terminals are not taken into account in this calculation.

Schemes B1 and B2 are attractive from the viewpoint of channel capacity, if envelope format is to be applied. However, figures indicating remote concentration are subject to discount, because they are based upon the less practical assumption that isochronous envelope-applied traffic is also remotely concentrated. The situation of anisochronous middle-speed traffic is as unfavorable as that of scheme A2.

Channel capacity is one of many possible facets to be compared. Therefore it is rather difficult to choose one best scheme based on this one factor only.

4.2.2 Error rate, adaptabilities etc. Error rates per the data digit of terminal speed depends, of course, on the sample multiplicity, as listed in a column of Table 2.

The listed adaptabilities to DTE and PCM transmission system are based upon the usage of 8 bit CCITT codes and the matching to 8 bit character in the multiplexed channel, respectively.

The character synchronization on the side of the terminal can be handled by various methods. Typical location of the function is indicated in Table 2.

4.2.3 Cost comparison of typical cases. Generally speaking, the result of cost comparison depends very much on various conditions such as the choice of system structure and the cost estimation of hardware components. These conditions in this comparison are set according to the prediction of data service demand in Japan and the latest hardware technology available in Japan. Referring to Figure 1, it is assumed that 40% and 60% of all data traffic are to, and not to be handled through, the 1st MPX, respectively. CLC traffic is not considered.

Three classes, A1, B1 and C1 of Table 2, are treated in the numerical comparison of relative cost-per-terminal of local subnetwork from DCE to DSE of the first switching stage (LS), as illustrated in Fig. 2. The reason for relatively high cost of class C1 is as follows:

(1) Traffic concentration in the MPX stage seems difficult and the number of 2nd MPXs is relatively large. In this comparison, therefore, the adoption of remote line concentration is assumed only to (A1) and (B1).

(2) DCE of envelope mode is expensive because of code signal receiving circuit for subscriber line loop utilized for maintenance and test of DCE from DSE.

(3) The multiplexing circuit at MPX is expensive because envelope processing facilities are included there.

(B1) is more expensive than (A1) in Fig. 2 because of the cost increment due to the partial envelope handling around a subscriber line. However, the difference is insignificant, considering the possible fluctuation of background conditions. Furthermore, the total cost of (A2) is indicated as an arrow attached to the histogram of (A1). This cost difference does not seem a definite factor in choosing Class A2, considering the similar conditions. It is, generally speaking, necessary to account for the average cost per line of trunk network portion, in order to make overall cost comparison of various modes. However, the factors of transit exchange (DSE) and trunk transmission facilities seem relatively small. This observation is partially supported by the fact that the portion of transmission facilities is relatively small in a local subnetwork as illustrated. The portions of packet switching (parts of CCE and CPU) are treated as a constant part, assuming the ratio of packet/circuit switching is fixed at 30%/70%.

## 5. Discussions and Estimations

Many factors are relevant to the choice of multiplexing scheme, as described above, and it seems rather difficult to obtain a straight-forward optimum solution. Conditions such as (i) terminal speed distribution, (ii) geographical distribution of terminals and (iii) the expected various network qualities (e.g. error rate, flexibility etc.) could differ from country to country. Anyway, a compromise between standpoints of economy and network flexibility is the basis of an individual optimum network.

The following is an overall discussion and estimation on the result of comparisons of §4, assuming application to Japanese domestic pulbic data service.

(1) Class C (envelope-interleaved) would be suitable to countries (regions) where isochronous medium-to-high speed data traffic demand is dominant, even though it is expensive in the assumed boundary conditions, because of the complexity of envelope

processing hardware around anisochronous data terminals on subscriber lines.

(2) Class A (bit-interleaved) seems to realize the simplest hardware structure of DSE and DCE (except that of envelope-handling type). The easy application of remote line concentrator results in partial compensation for channel capacity decrease due to multiple-point sampling.

It also became clear that a too high channel capacity of multiplexed channel (and MPX) might cause a longer average subscriber line distance or larger overhead due to unfilled multiplexed channel and anyhow become a resultant increment of the contribution to the per-terminal-cost. Therefore, the pursuit of too large channel capacity of multiplexed channel is not necessarily always effective in the pursuit of an overall economical network.

(3) Class C has the advantage of the possibility of handling the envelope in-channel controlling signaling of a two-level type, However, class A is not necessarily disadvantageous in this signaling aspect, because it can handle either separate common channel signaling associated with three-level transmission in a subscriber line, or in-channel separate-bit signaling (e.g. 8 kb/s control signaling attached to 48 kb/s message data). Therefore, the increment of per-terminal cost segment due to three-level signaling in class A (and class B for anisochronous data) cannot be considered as an essential disadvantage in cost comparison.

(4) Class B could not be rejected by a simple cost comparison, because the increment to calss A is rather small. However, Class A seems a little bit more suitable from some other viewpoints such as:

i) Flexibility (on homogeneous handling mode) to meet an unpredictable variety of terminal data speeds.

ii) Shorter synchronization recovery time.

iii) Better error rate in the multiplexed channel part.

(5) Multiplexing schemes illustrated in Table 2 are for 1,544 kb/s digital channel. However, the fundamental principle is merely by reducing channel capacity proportionally, easily applicable to 64 kb/s x n digital channels between 1st MPX and 2nd MPX/RLC, because the highest bearer rate is 56 kb/s, except for the case of 96 kb/s high speed FAX traffic, assuming a 48 kb/s message flow combined with an 8 kb/s signaling flow. Therefore, the calculation for Figure 2, in which 1st MPX is considered too, stands almost as it is.

(6) The above discussions on multiplexing schemes are for domestic network use. The processing of 64 kb/s digital channel basis from/to 1,544 kb/s digital data multiplexed channel at the international gateway station for international interworking, seems easily implemented without technical difficulties.

## 6. Conclusion

Several variations of multiplexing scheme are compared and estimated from various standpoints, in order to determine suitable multiplexing structures of a unified Japanese public data network, referring also to the CCITT Recommendations, which are based upon the studies of the Joint Wirking Party NRD.

The result of this multiplexing study includes the following:

(1) The bit-interleaved multiplexing scheme seems suitable from the viewpoint of overall economical installation of a unified digital data network.

(2) It seems possible to recommend the dedicated usage of 1,544 kb/s digital transmission channel as a digital multiplexed data channel in the major part of public digital data network, as well as the combined usage of 64 kb/s digital subchannels, e.g., in the rural and suburban area between 1st MPX and RLC/2nd MPX.

Class A1 of Table 2 was selected as the multiplexing scheme of a Laboratory Model which is currently in the stage of on-line program debugging, through putting emphasis on the possibility of economical network structure and feasibility of high-quality network bit error rate. The choice of the multiplexing scheme for the field trial model is, however, an important subject for further study.

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| (a) Terminal Speed | (b) Bearer Bit Rate | (c) | (d) Sampling Rate | (e) Sampling Multi-plication | (f) Remarks |
|---|---|---|---|---|---|
| 50b/s | 50b/s | | 2kHz | 40 | for Telex |
| 100 | 100 | aniso-chronous | 2 | 20 | |
| 200 | 200 | | 2 | 10 | |
| 1,200 | 1,500*/1,200 | | 12 | 8*/10 | |
| 2,400 | 3,000*/2,400 | | 12 | 4*/5 | |
| 9,600 | 12,000*/9,600 | | 12/48 | 1*/4*/5 | |
| 48k | 48k | iso-chronous | 48 | 1 | for multiple-message terminal |
| 96k(FAX) | 96k | | 96 | 1 | for high-speed FAX |
| | 192k | | 192 | 1 | for channel between packet exchange |
| | 1,536k | | 1,536 | 1 | |

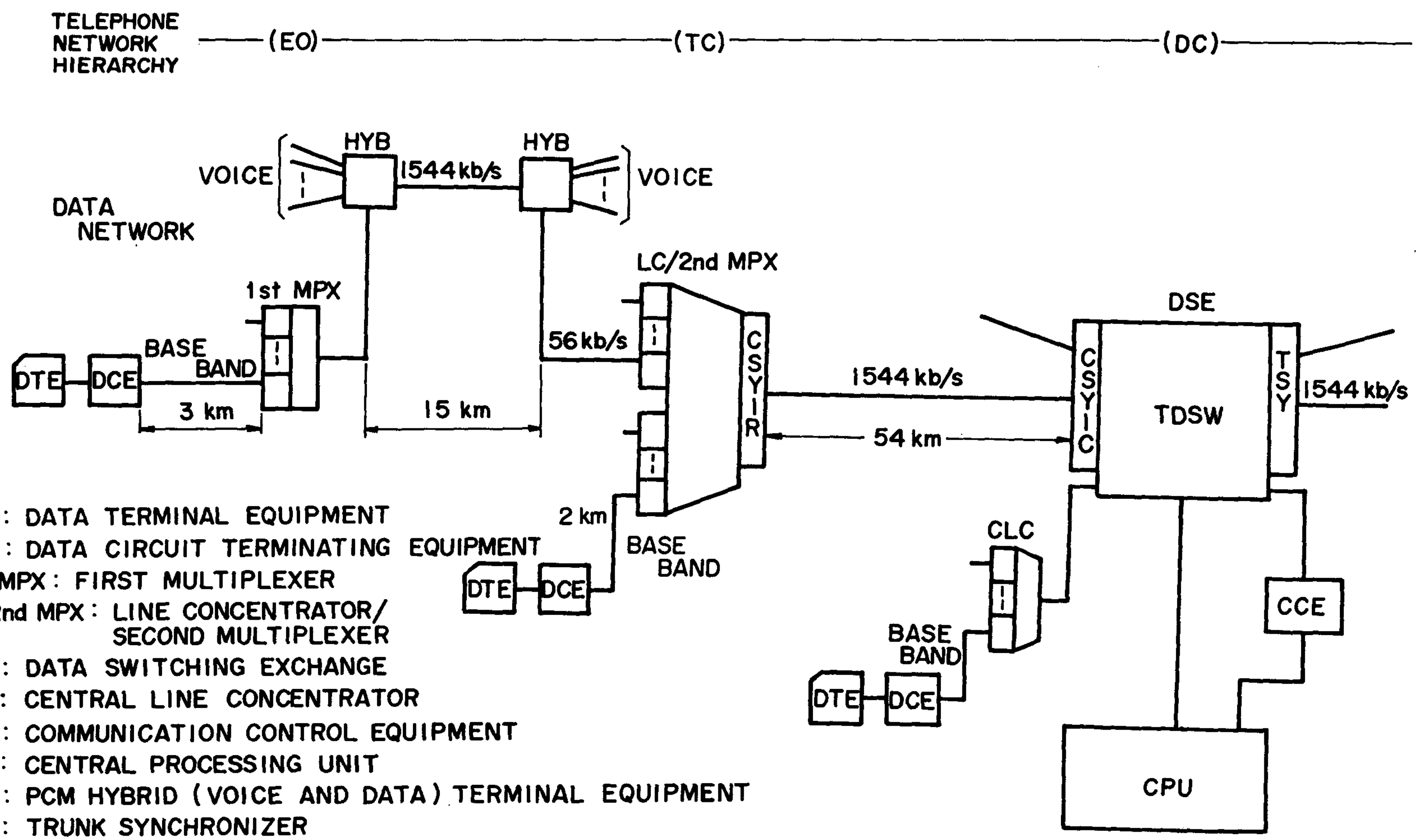
* (8+2)bit envelope mode application for experimental evaluation

Table I Correspondence between Terminal Speed & the Sampling Bit Rate of Class AI Scheme

Table 2 Comparison of multiplexing scheme for both isochronous and anisochronous data

| FORMAT | | SWITCH-ING BASE | BASIC FRAME RATE | ENVELOPE FORMAT | BEARER RATE 50*1 ~ 200*1 | BEARER RATE *2 2400 | BEARER RATE 1200*1 9600*2 | BEARER RATE *2 48k | FRAME FORMAT (1,544 kb/s) | CHANNEL CAPACITY WITH LC *3 | CHANNEL CAPACITY WITHOUT LC *3 | ERROR RATE | ADAPTABILITY DTE | ADAPTABILITY PCM | CHAR SYNC | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | $A_1$ | BIT | 2 kHz | 8+2 | 2kHz | 12kHz | | 48kHz | 2 kb/s; 12 kb/s; 0.5ms | 770 | *4 (170) | *5 $T_s \le 2.4^{kb}$, $E \le 10^{-7}$ / $T_s \ge 9.6^{kb}$ $E = 10^{-6}$ | YES | YES | DTE | NTT' Lab. Model |
| | $A_2$ | | 2.4 | | 2.4 | | 9.6 | 48 | 2.4 kb/s; 9.6 kb/s; 0.42ms | 1356 | (267) | | YES | YES | DTE | |
| B | $B_1$ | EV/BIT MIXED | 0.4 | 6+2 | 2 | 3.2 | 12.8 | 64 | 3.2 kb/s; 2 kb/s; 2.5ms | 1147 | (219) | $T_s \le 200^b$ $E \le 10^{-7}$ / $T_s \ge 2.4^{kb}$ $E = 10^{-6}$ | NO | YES | DCE | |
| | $B_2$ | | 0.3 | 8+2 | 1.8 | 3.0 | 12 | 60 | 3 kb/s; 1.8 kb/s; 3.33ms | 1234 | (235) | | YES | NO | DCE | |
| C | $C_1$ | EV | 0.1 | 6+2 | 0.8 | 3.2 | 12.8 | 64 | 0.8 kb/s; 3.2 kb/s; 10ms | (1417) | 257 | $E = 10^{-6}$ | NO | YES | DCE | NRD |
| | $C_2$ | | 0.1 | 8+2 | 0.75 †+0.05 | 3.0 †+0.2 | 12 †+0.8 | 60 †+4 | 0.8 kb/s; 3.2 kb/s; 10ms | (1417) | 257 | $E = 10^{-6}$ | YES | NO | DCE | † Overspeed |

note *1 bit rates of anisochronous data
*2 bit rates of isochronous data
*3 with/without LC: with/without terminal traffic concentration at LC
*4 The parenthesis indicates the less practical case
*5 Ts: Terminal Speed
E : Error rate




DTE : DATA TERMINAL EQUIPMENT
DCE : DATA CIRCUIT TERMINATING EQUIPMENT
1st MPX : FIRST MULTIPLEXER
LC/2nd MPX : LINE CONCENTRATOR/ SECOND MULTIPLEXER
DSE : DATA SWITCHING EXCHANGE
CLC : CENTRAL LINE CONCENTRATOR
CCE : COMMUNICATION CONTROL EQUIPMENT
CPU : CENTRAL PROCESSING UNIT
HYB : PCM HYBRID (VOICE AND DATA) TERMINAL EQUIPMENT
TSY : TRUNK SYNCHRONIZER
CSY-C : CONCENTRATOR SYNCHRONIZER-CENTRAL
CSY-R : CONCENTRATOR SYNCHRONIZER-REMOTE
TDSW : TIME DIVISION SWITCH

note : Distances between offices are average values in japan

FIGURE 1 Local Subnetwork model

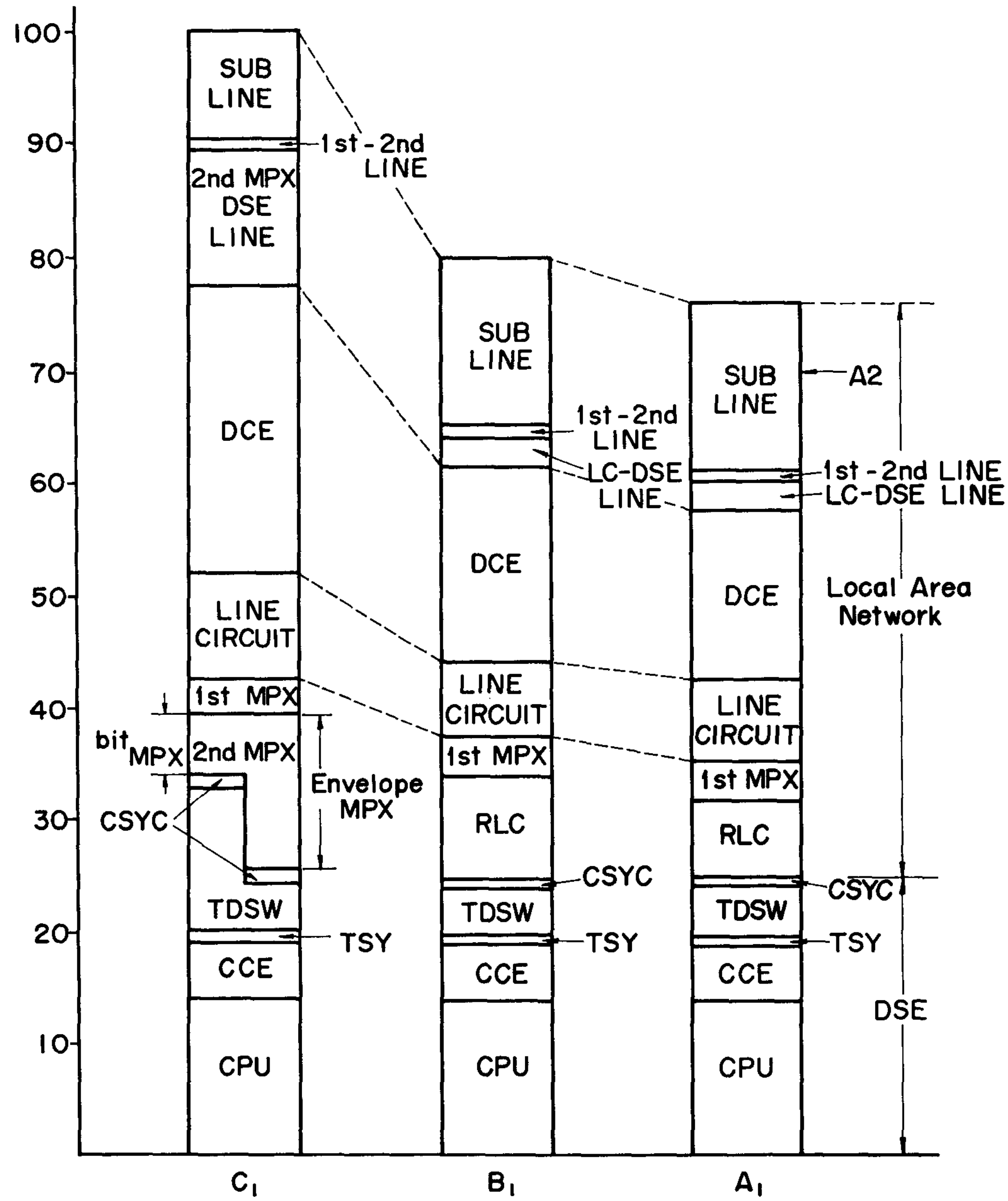



Figure 2 Relative local subnetwork scheme cost per terminal