Invited paper

Recent Development in Digital Communication Systems in Japan

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The sophisticated demands of modern society have generated a growing need for various kinds of communication services, such as data, video and mobile telephone, in parallel with conventional telephone services. However, demand for these new services is relatively light and unpredictable at this stage, when compared with conventional telephone traffic.

Consequently, the optimum solution to this situation would seem to lie in an economical digital network, which can cope with the new services, while at the same time providing the economy required for conventional services.

To realize such facilities, research on PCM integrated networks was initiated in Japan about 15 years ago. Conclusion drawn from early work suggested that the key to resolving the problem was directly linked to progress in component and materials research. Thus, progress in semi-conductor technology, such as the advent of the IC, has brought us viable digital data networks. Now, recent progress in LSI and optical fiber technology promises to bring us economical integrated services digital networks.

This paper provides insights into the background of digital communication progress in Japan. Areas covered include recent breakthroughs in components and materials; a brief history of digital network development, e.g. PCM, data and integrated; and some highlights of recent work, such as the PCM-400M and optical fiber transmission systems.

1. Introduction

The ever-sophisticating demands for communication in today's society have been gradually expanding. This expansion has affected conventional human-to-human communication and has seen a growing utilization of machine-to-human, and even machine-to-machine communication. The modes of communication have also expanded from telephone voice to include data and video. The closely-integrated character of modern social activities, over a widening area utilizing various forms of information, has lead to an unpredictable pattern of traffic fluctuation.

This situation has steadily stimulated demands for better transmission and more flexible networks. The introduction of stored program controls into a network has provided network flexibility with regard to service functions. However, realizing this flexibility and quality for transmission has required the digitalization of communication networks.

On the other hand, in spite of the rapid growth in communication modes, the majority of the communication will continue to be occupied by conventional voice communication. Therefore, any new communication network will have to be economical enough for use by conventional modes as well. Fortunately, recent progress in LSI and optical fiber technology has brought us to the brink of solving the contradictory problem of satisfying both economy and flexibility, in opening the way for a viable digital communication network.

This paper will describe the background surrounding digital networks from demands to technical progress. It will also provide a brief history of research and development in digital communication networks, as well as some highlights of recent digital transmission technological progress in Japan.

2. Background of Digital Network

The demand for advanced as well as various types of information processing has brought about rapid development of data communication systems. As a result, data communication systems are, and will continue to be, playing an increasingly important role in society. Many of these systems use existing telephone and telex links as the means of communication between on-line computers and data terminals. The diversity of data communication services has brought about demands for better transmission quality and shorter connection time, areas which are not satisfactory in existing telephone or telex networks. This situation is what brought about the development of a new digital data switching network.

Aside from this, dwindling energy resources will serve to make communication more important in the activities of future society. The modes of communication have expanded from telephone to data and video. Consequently, transmitted information is on many frequency bands; and traffic is prone to considerable fluctuation.

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In these transmission systems, flexibility of transmission is preferable since it provides a means to avoid overtraffic in any one type of transmission. Digital transmission has latent flexibility combined with a time division switching system as will be described later.

It is well known that a channel capacity C is expressed in the form:

$$C = W \log \mathrm{S/N}, \tag{1}$$

where W is the frequency band and S/N is the signal to noise ratio. In the digital transmission line, W and S/N are easily interchangeable. And if we expand to an n channel network with a switching system from a simple transmission line channel, capacity C becomes

$$C = nW \log \mathrm{S/N}. \tag{2}$$

In a digital network, (n, W) $(n, \mathrm{S/N})$ are relatively easily interchangeable as are $(W, \mathrm{S/N})$ in digital transmission. Mixed bearer rate traffic handling is one application of (n, W) interchangeability. Overall network control by changing a bit rate, sacrificing quantizing noise, is another application of $(n, \mathrm{S/N})$ interchangeability.

An apparatus with complex control logic circuits is necessary to implement these applications into a network.

Recent progress in semi-conductor technology will make complex logical circuits more and more economically realizable. On the other hand, to transmit a video signal requires 1000 times the bit rate of an ordinary telephone signal. Therefore, economical wide frequency band transmission will be necessary before this type of communication can become as common as the telephone. Optical fiber transmission systems hold great promise for such use. In such systems, signal transmission is sent by energy rather than wave form. Therefore, digital transmission is compatible with the system.

The digital system, as mentioned above, seems to be the most suitable for future communication demand. The key to economic realization of the system is development of components, especially semiconductors.

A digital communication network has a number of merits. The effect of these merits is maximized, however, in integrated digital networks. There are two kinds of integrations in digital communication networks. They are the integration of transmission and switching, called integrated digital networks, and the integration of services; for example, telephone, data and video, called integrated service digital networks.

Integrated digital networks, in which digital coded signal transmission and its switching are carried out on a time-division basis, is expected to make possible an economical communication system with low loss and without the cumulative increase of quantizing noise.

On the other hand, integrated service digital networks in which different kinds of signals are transmitted in a one bit stream are expected to provide a flexible communication system with mixed bearer rate traffic handling control.

3. Digital Communication Network

The first model of the PCM switching system—DEX-T1—, and the network synchronizing system were successfully completed in 1967 and showed satisfactory testing results.

In evaluating this exploratory system, the following three conclusions were drawn for further development of a digital communication network.

(1) The digital communication technique may be affected directly for data communication.

(2) Further development of components and materials to reduce the cost of a digital telephone network is necessary for both switching and transmission.

(3) Remote control techniques through digital transmission links may be applied for remote switching control.

As a result of the first conclusion, the digital data communication network DDX has been developed.

The aim of data switching network development is to provide an economical network with qualities and facilities suitable for data communication. Toward this aim, a circuit switching system and a packet switching system were developed in parallel. To realize a circuit switching system, the DDX-2 field test system has been developed. The DDX-2 circuit switching system is a digital switching system integrating digital transmission and a time division switch. The DDX-2 packet switching system is a kind of store and forward switching network which has the potential to fill a variety of data communication needs, due to its speed and code conversion feasibility. With regard to the packet switching system, a DDX-2 field test system connecting computers installed at two universities—Tokyo University and Kyoto University—as shown in Fig. 1, is now working successfully.

There are a circuit switching network, a packet switching network and a point-to-point digital leased circuit in the new data network. Each of these networks provides an optimum scope of application in different data communication categories. Therefore, users may select either network, according to the optimum application field. The application fields of new data networks, based on network cost evaluation, are shown in Fig. 2. Since circuit switching involves call set-up and clean-down procedures, circuit switching is suitable for relatively long message transmission; such as message communication, bulk data transmission and digital facsimile. On the other hand, since packet switching does not require a physical communication link and is concerned with message, packet switching is suitable for relatively short message transmission, such as inquiry response and cashless terminal communications. Leased circuits can be utilized for point communications. However, the circuit switching network may be utilized for point-to-point communication when the volume of messages per month is relatively small. Each of the

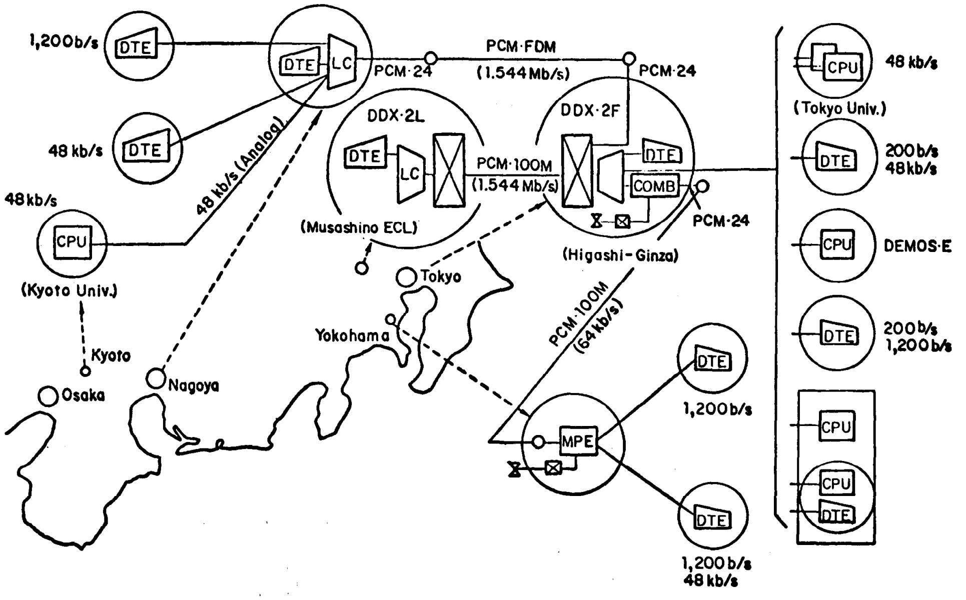

Fig. 1 DDX·2 field trial network.

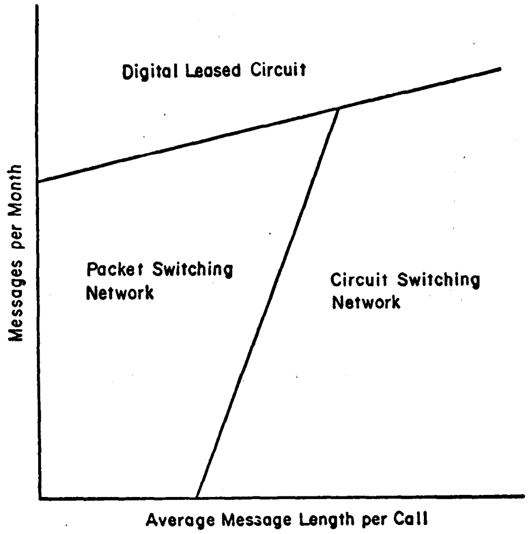

Fig. 2 Application field.

switching systems can be expanded into a nationwide network, accommodating terminals suitable for the network.

The DDX-2 circuit switching system employs time division switches. These switches are the result of recent development in IC device technology which has made possible the economical time division switch realization, as far as data application is concerned.

The DDX-2 circuit switching system handles mixed bearer rate traffic. In this regard, the time division switching configuration may be selected, taking the composition of this mixed bearer rate traffic into consideration. The DDX-2 switching configuration is Space-Time-Space (STS), in order to efficiently use the multiplexed channel by varying the channel division for each speed. In the DDX-2, the multiple sampled transmission process was adopted for Start-Stop data. Then three bearer rates were provided for 50 b/s – 48 Kb/s data, in order to facilitate the handling of the mixed bearer rate traffic. An octet interleaved multiplexing scheme was adopted to assure adequate sharing between the digital data and digital telephone switches.

The subscriber loop signaling operations of the DDX-2 are designed to meet CCITT Recommendations X-20 for start-stop transmission service and X.21 for synchronous transmission service. This system also incorporates a base band transmission system, NRZ, below 9.6 Kb/s and bipolar one at 48 Kb/s. The inter-office signaling system employs 64 Kb/s common channel signaling.

The DDX-2 packet switching system, shown in Fig. 3, consists of packet switches (Ps) which accommodate packet mode terminals and transit packets, a packet multiplexer (PMX) for packet assembly and disassembly functions (PAD), and transmission media connecting these units.

A packet switch can accommodate sixty-four 48 Kb/s lines. The packet multiplexer is a specially designed low cost mini-computer, which handles the packet assembly and disassembly functions, and has 255 terminal ports shared by customers. The packet switches and packet multiplexer can employ both analogue and digital lines for network configuration flexibility. The analogue line accommodation facilitates network expansion during

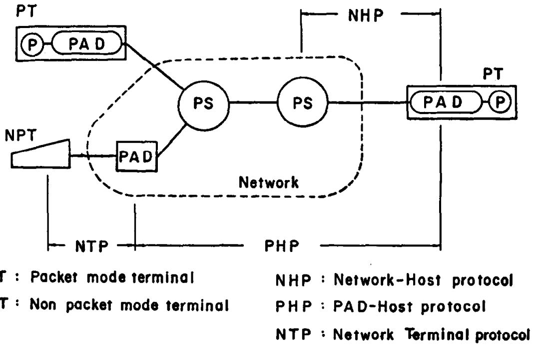

Fig. 3 Network structure.

the initial stages of network build up, and the digital line accommodation helps to reduce transmission costs.

The packet mode terminal interface consists of network-host protocol and PAD-host protocol modules. The network-host protocol module offers the virtual call procedure specified in CCITT Recommendation X.25. The PAD-host protocol module specifies the procedure for shared operations between a packet mode terminal and a character mode terminal. The PAD-host protocol module control information is contained in the user data field of packets as defined in CCITT Recommendation X.25.

The character mode terminal interface consists of call establishment procedure and data transfer procedure modules. The call establishment procedure module meets the specifications in CCITT Recommendation X.20 and offers a V series interface for existing terminals. This ensures character mode terminal interface compatibility with packet switching and circuit switching services.

4. Recent Progress in Semi-Conductors for Digital Network

Now, let us turn our attention to the second conclusion. Namely that, "Further development of components and materials is necessary to reduce the cost of a digital telephone network for both switching and transmission." In line with this, the author would like to touch on some highlights of recent progress in semi-conductors.

Fig. 4 shows that recent progress in semi-conductors has circumvented the cycle time limitation of the core memory.

The price of memories has also been decreased substantially by the semi-conductor memory as shown in Fig. 5. This has been achieved through variation of memory LSI configuration as shown in Fig. 6, as well as through high density assembly techniques.

The situation with regard to IC logic gates is the same as that of IC memories, as shown in Fig. 7. Reliability trends of the IC in electronic switching systems are shown in Fig. 8.

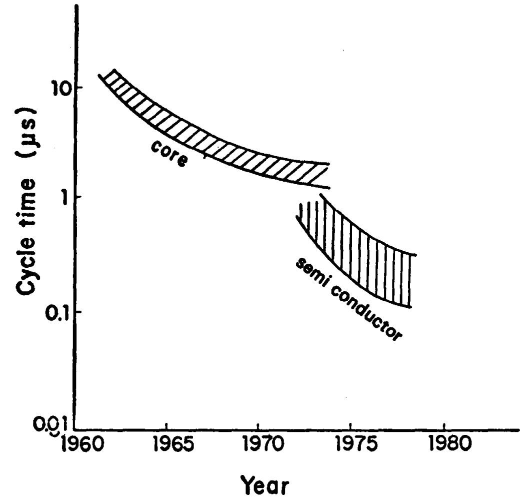

Fig. 4 Cycle time of the memory devices.

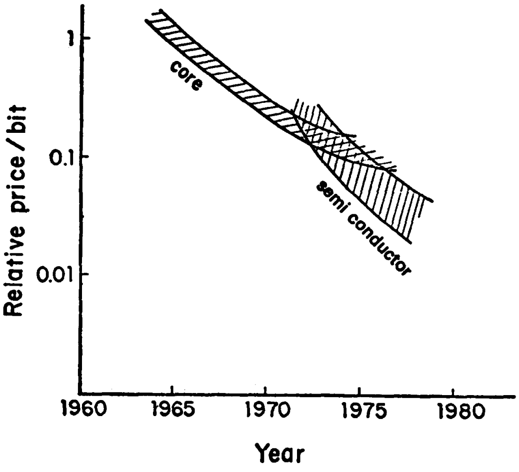

Fig. 5 Prices of the memory devices.

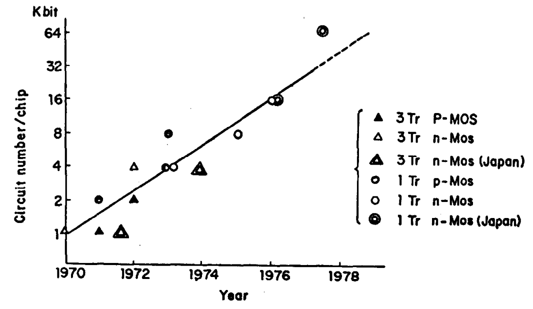

Fig. 6 Memory LSI complexity with time.

5. Digital Transmission Systems

Various types of digital transmission systems have been

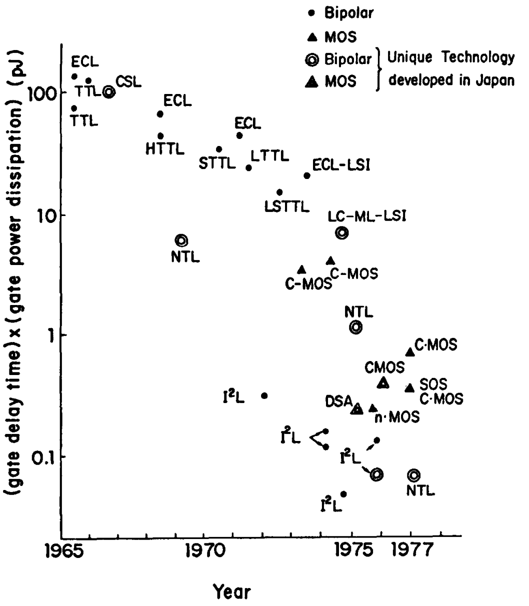

Fig. 7 Reduction in delay power product of logic gates.

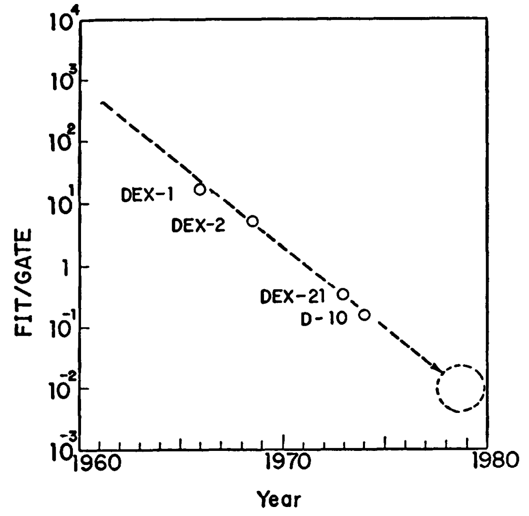

Fig. 8 Progress in reliability of IC in electronic switching equipment.

developed by NTT. These systems are constantly being reevaluated so as to realize higher quality and more economical services to cope with the ever-increasing demands for data transmission and video transmission services, as well as telephone services.

Digital coaxial cable transmission systems have been developed to expand transmission capacity, since the introduction of the short-haul systems with transmission capacities below 100 Mb/s was completed by 1974. In January 1977, a new coaxial digital transmission system, the PCM-400M system, was put into commercial use between Osaka-Kobe (48 km) and Kobe-Himeji (66 km).

The PCM-400M system is the world's first long-haul, large capacity digital transmission system, designed to serve as the mainstay circuit in a transmission network.

The PCM-400M system was designed to operate at a bit rate of 400.352 Mbit/s and can transmit 5,760 telephone channels or 60 interframe coded 4 MHz color television signals over one 2.6/9.5 mm coaxial cable.

The error rate for a 2,500 km circuit length is designed to be less than 10^{-8}, which satisfies very high quality television signal transmission requirements. There is no restriction on transmission distances in actual practice, in the case of telephone and/or data transmission, which requires a 10^{-6} error rate or better. However, it should be noted that there is very little difference in repeater costs when obtaining a 10^{-8} rather than 10^{-6} error rate. The main circuits of repeaters are composed of thin film hybrid integrated circuits (IC's) in which thin film L, C and R elements are formed on the same substrates. Consequently, not only circuit reliability and productivity, but also circuit performance and uniformity are improved. Newly-developed transistors with $f_t = 8$ GHz are mounted on the hybrid IC's through thermal compression bonding.

Digital radio relay systems in the quasi-millimeter wave band have been studied to realize the expansion of transmission capacities after the development of 15 GHz analogue radio relay systems in 1966.

NTT recently put a 20 GHz band digital radio relay system into operation on the Tokyo-Yokohama (29 km) and Osaka-Kobe (37 km) routes.

The 20 GHz radio system using the 17.2–21.2 GHz band is designed to carry 400 Mb/s digital signals using 4 PSK-coherent detection. It can transmit about fifty thousand telephone channels over long-haul trunks. The nominal repeater spacing is about 3 km in Japan, despite the heavy rainfall rate.

The allowable circuit interruption objective is 0.3%/2,500 km, chosen on the basis of coaxial cable system and FDM-FM microwave radio relay system requirements. One-third of this value (0.1%) is budgeted for interruption due to rainfall. The rain attenuation margin required to satisfy this objective is about 46 dB when the span length is 3 km at 20 GHz. The threshold error rate for system failure due to propagation was selected to be 10^{-6} from the standpoint of data, band compressed video and voice transmission.

6. Optical Fiber Transmission

Recent progress with optical fibers in Japan has permitted us to obtain 0.5 dB/km with impurity below 10 ppb of OH basis. In mass production, 2–3 dB/km is being attained.

Optical fibers are characteristically thin, light, flexible, non-inductive, non-crosstalk, low loss and wide band. They are made of silicon which is readily available almost anywhere.

Optical fibers are normally 0.1 mm in diameter and are composed of a core with high ε glass surrounded by cladding with relatively low ε. Light waves are transmitted by repeating complete reflection in the core. Three types of the optical fiber transmissions compared with conventional coaxial cable transmission are shown in Fig. 9.

Optical fiber transmission can be applied to almost all areas of communications because of such excellent fiber characteristics as small diameter, light weight, immunity to electro-magnetic interference and crosstalk, low losses and wide bandwidth. During the past 6 years, optical fiber losses have decreased remarkably and now stand at 0.5 dB/km, as shown in Fig. 10.

Recent techniques for epitaxial growth and processing have improved the semi-conductor laser life which is now approximately one million hours. Several optical transmission systems for public digital communication are actively being studied at NTT. A medium capacity system with 32–100 Mb/s will probably be the first practical system of this type in Japan. The initial trial of an optical fiber transmission system, using a 32 Mb/s laser diode system, has been under consideration since late 1975. Related work is presently going on at the Yokosuka E.C.L. This trial is expected to provide the information necessary for evaluating the applicability of optical fiber transmission technologies to NTT's telecommunication networks.

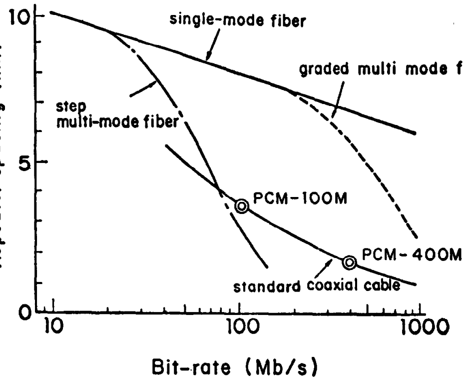

Fig. 9 Repeater spacing of various fibers.

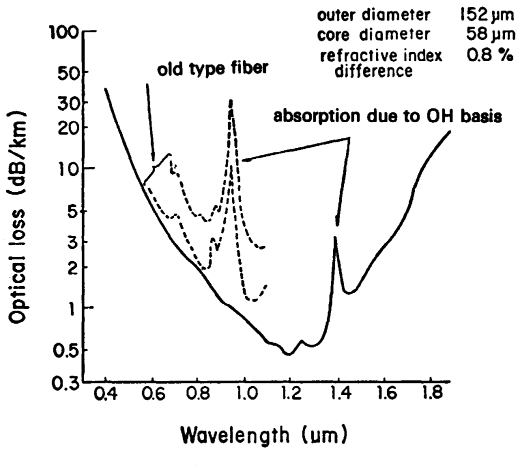

Fig. 10 Optical loss characteristics in new step type multi-mode fiber.

The 32 Mb/s medium capacity digital fiber system employs low loss 8 km long cables, incorporating eight step-index fiber strands, and is installed in the cable tunnel at the Yokosuka Laboratory. The fibers have a 60 μm core and 150 μm outer diameter with a 0.01 refractive index difference. Eight fibers were cabled in a 1 km unit around a central tension member. The 64 fiber pieces installed in the cables had an average loss of 3.0 dB/km at 0.83 μm with a 0.4 dB/km standard deviation.

The bandwidth measured with a 1 km piece was 45 MHz on the average and had a 5.6 MHz standard deviation. The average splicing loss and corresponding standard deviation was 0.18 dB and 0.11 dB, respectively. Overall losses in 8.4 km spliced fibers ranged between 22–26 dB. Fibers and splicing joints with more uniform loss and frequency characteristics will be important for realizing a more accurate system design. It is also necessary to evaluate fiber cables under actual application conditions. Furthermore, power feed and fiber fault location should be one of the next areas of through investigation.

The 32 Mb/s repeaters, separated by about 8 km fibers, were evaluated and found to provide satisfactory performance. These repeaters employ semi-conductor lasers, avalanche photodiodes and electronic signal regenerators. Six-repeater line experiments involving system reliability tests are being carried out over a 50 km long system.

7. Satellite Communication

In future satellite communication systems, digital transmission systems, such as Time Division Multiple Access (TDMA) systems, will gradually replace conventional analogue transmission systems. This is because they offer advantages such as; increased channel capacity per transponder, operational flexibility and mixed information transmission. NTT plans to use TDMA as the multiple access method in a medium capacity domestic satellite system. Two types of TDMA systems have been developed for *K* and *C* band satellite communications.

The TDMA system for the *C* band (TDMA-100M system) is expected to be used for communications throughout Japan. Communications with remote islands, which are about 1,000 km from the mainland, are not entirely satisfactory and are difficult with conventional terrestrial communication systems. The other TDMA system (TDMA-60M system) for *K* band satellite communication will be employed to back up the highly developed terrestrial circuits between major cities in Japan. This system will help to overcome network breakdowns due to natural disasters such as earthquakes and typhoons.

The trial equipment for these TDMA systems has been manufactured, and performance evaluation using a test loop inside an earth station has been carried out. Field tests, using the experimental medium capacity communication satellite (named Sakura), are being carried out.

8. Conclusion

Progress in semi-conductor technology, such as the advent of the IC, has brought us viable digital data networks. As a result, digital data switching services including both circuit and packet will be put into commercial use in 1979.

In addition, recent progress in LSI and optical fiber technology has brought us to the brink of solving the problem of satisfying both economy and flexibility in opening the way for a viable integrated digital communication network. Field trials of optical fiber transmission and digital integrated PCM switching networks are initiated.

References

1. K. Hanawa, et al. "An Exploratory PCM Switching System [DEX-T1]" Rev. of the E.C.L., NTT, Japan **16**, 3–4 (1968), 253.
2. R. Nakamura, et al. "DDX-2 Digital Data Circuit Switching System" Rev. of the E.C.L., NTT, Japan, **25**, 7–8 (1977), 635.
3. Y. Mima and M. Kato, "Development of the Circuit Switching System for Digital Data Network", Rev. of the E.C.L., NTT, Japan, **25**, 7–8 (1977), 629.
4. M. Nakamura, "DDX-2 Packet Switching Network", Data Communication Network Conference in London, (May 1977).
5. M.Ejiri and H.Kasai, "Commercialized PCM-400M System", Japan Telecommun. Rev., **19**, (1977), 199.
6. Y. Nakamura, et al. "20 GHz Digital Radio-Relay System", ICC'77, (1977), 40.3–88.
7. H. Mizuguchi, "Optical Fiber Transmission System Research for Public Telecommunication in Japan", IOOC'77, Tech. Digest. (July 1977), 503.
8. T. Miki, et al. "Initial Trial of Optical Fiber Transmission Systems in NTT: Overview", IOOC'77, Tech. Digest. (July 1977) 541.