Packet Communication Ultra-Small Aperture Terminal System for the Hokkaido Integrated Telecommunication Network

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***Abstract*—Three aspects of a new minimum cost, high reliability system strategy for the Hokkaido Integrated Telecommunication (HIT) network, in which real time operation is not demanded, are examined. These are: 1) a packet communication ultra-small aperture terminal (PC-USAT) system, which contains a method for overcoming the satellite links rain attenuation discontinuities; 2) an optimum rain margin technique and the 14/12-GHz band rain, snow attenuation, and site diversity (SD) experiments; and 3) a low-bit-rate medical information and still-picture simultaneous transmission system.**

I. Introduction

Satellite communication technologies are now highly developed, and high quality, distance-independent services that have expanded over very wide areas [1]. In particular, low cost, very small aperture terminal (VSAT) [2] networks for data, voice, and video communications have expanded widely with new services and new applications.

In Japan, the Hokkaido Integrated Telecommunications (HIT) network has been constructed with satellite communication systems and newly built optical fiber or low cost SHF band terrestrial radio networks. By using the HIT network, economical and highly functional services, including expansion of the network to rural areas, can be realized [3]–[6]. Two information transmission modes are considered, i.e., 1) small capacity two-way medical or educational information transmission, and 2) medium capacity two-way information transmission. In the first mode, an ultra-small aperture terminal (USAT) is used and can be applied to many services. The second mode can be used for transmission of visual medical information, e.g., computerized tomography (CT) scan images and X-ray photographs.

As for the system design of the HIT network, it must be constructed as economically as possible. Furthermore, to apply the 14/12-GHz-band VSAT system, it must first overcome rain attenuation discontinuities of satellite links, which is a most difficult problem for the 14/12 GHz band.

To resolve these problems, several strategies were considered: 1) networking with satellite communication and optical fiber or low cost SHF terrestrial wireless networks; 2) the packet communication ultra-small aperture terminal (PC-USAT) system [7], [8], where the packet length is changed in accordance with rain attenuation and thereby allowing a rain margin of several dB; 3) low bit rate medical information (e.g., electrocardiogram, temperature, blood pressure, pulse rate, etc.) and a still-picture simultaneous transmission system; 4) optimum design for determination of the rain margin; and 5) introduction of site diversity (SD)[9]. In the following sections, the items (2)–(5) are discussed.

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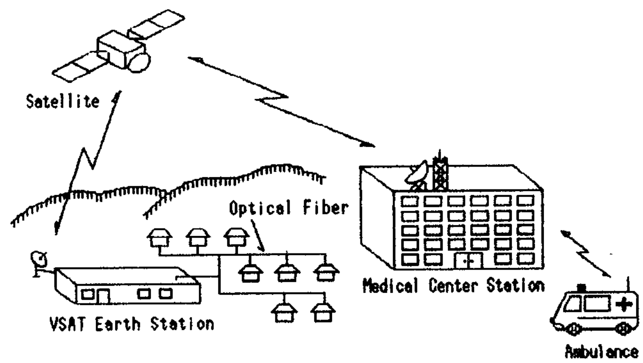

Fig. 1. HIT network concept.

II. Hokkaido Integrated Telecommunication (HIT) Network

A. Concept

The concept of the HIT network is shown in Fig. 1. A small (1–2 m) earth station receives signals from a large (3–5 m) earth station using a 14/12-GHz-band satellite and distributes the signals to optical fiber or SHF band terrestrial radio networks and subscribers. The large earth station (medical or educational center) is located in a big city and small earth stations may be located in remote areas.

B. Application

Medical data transmission services from subscribers to medical centers by using the HIT network is attractive for patients in villages among the mountains or in remote places. In the HIT network, for example, a compact and portable-type man-machine-interface (MMI) detects and digitalizes the patient medical information, e.g., electrocardiogram, temperature, blood pressure, and pulse rate at the subscriber's home

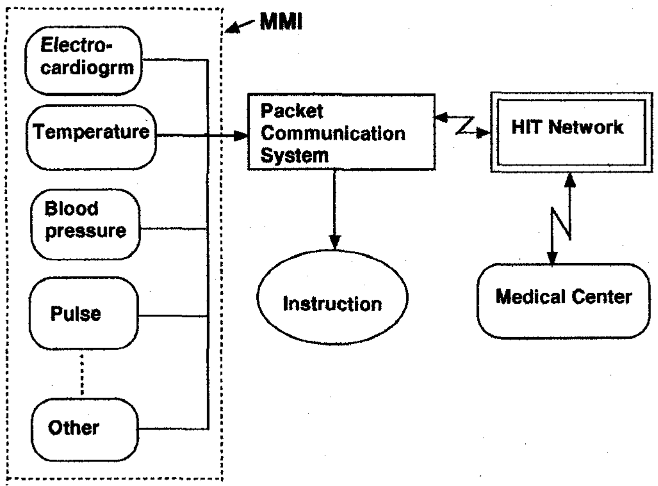

Fig. 2. Medical information transmission service example.

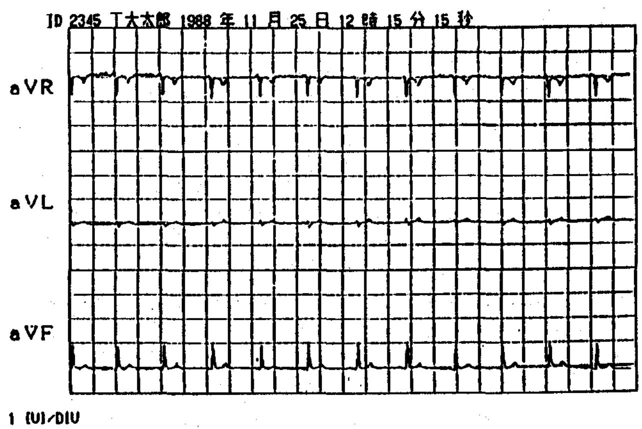

Fig. 3. Example of medical information (electrocardiogram).

(see Fig. 2). By using an optical fiber network or a low cost SHF terrestrial radio network, these data, at a bit rate of about 9.6 kb/s, are gathered and multiplexed to a small earth station in the village and then transmitted via satellite to a medical center with a bit rate of 64 kb/s. In the medical center, the medical information and other data are stored and a doctor or other experts can look at the data. If abnormal data are observed, the medical center can give instructions to the patient. This system can contribute to future home care systems or remote care systems.

C. Example

An electrocardiogram has twelve measuring channels. The input impedance is 50-M-ohms and the time constant is 3.2 seconds. Body temperature and respiration rate can be measured by thermistor, and blood pressure can be measured by a semiconductor distortion gauge. The analog data are converted by an analog to digital (A/D) converter and processed by a 32-bit microprocessor. The compact and portable type MMI size is 25 × 25 × 10 cm and its weight is less than 1 kg. An example of a measured electrocardiogram is shown in Fig. 3. By using this network, economical and highly functional services can be provided [3]–[6].

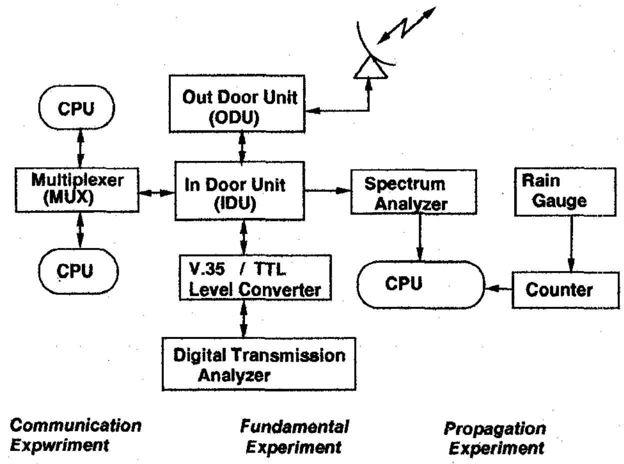

Fig. 4. Block diagram of experimental earth station.

III. System Design Considerations

A. Conventional Packet Communication System

In the HIT network, the packet communication system [2] was introduced at the R&D stage, because of 1) the less severe requirement of real time operations, 2) its efficient utilization of the frequency spectrum, 3) short circuit exclusive time, 4) a large number of subscribers, and 5) reductions in the network cost.

To confirm the fundamental characteristics of the conventional packet communication system, an experiment via the Japan Satellite Systems Inc. satellite (JCSAT) was carried out. The experimental earth station (ES) block diagram is shown in Fig. 4. The information bit rate of the satellite links is 64 kb/s by using QPSK (Quadarature Phase Shift Keying) modulation techniques. Two-way packet communication experiments in one earth station can be carried out by using two TDM slots of a multiplexer. Two 9.6-kb/s digital data are used in the satellite experiment and are multiplexed and demultiplexed in the multiplexer. To confirm the HIT network information transmission, medical information transmission experiments were carried out. The electrocardiogram analog signal is converted to a digital signal by an A/D converter and transmitted via satellite to the medical center where the data are processed. In this experiment, i.e., using a conventional packet system, some problems occurred: 1) optimum packet size must be selected under low carrier to noise power ratio (C/N) values or rain attenuation levels, 2) ACK (Acknowledgment) or NACK (Not Acknowledgment) signals of packet communication can not be returned during heavy rain attenuation. These problems can be solved by using the PC-USAT system.

B. PC-USAT System

The PC-USAT system is based on an improved packet communication system. The PC-USAT system contains a method for overcoming the satellite links rain attenuation discontinuities, which is the most difficult problem confronting the 14/12-GHz-band VSAT satellite system. In the proposed PC-USAT system, the packet length is changed in accordance

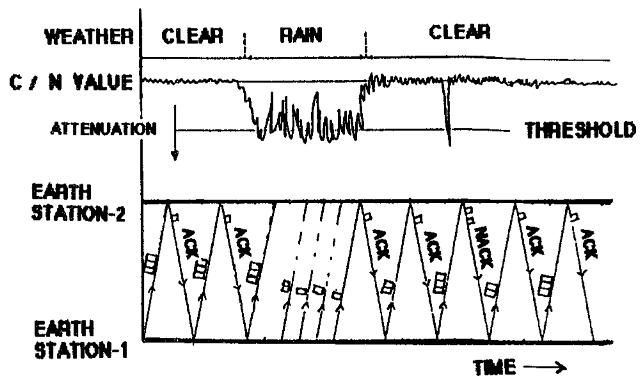

Fig. 5. Concept of PC-USAT system.

TABLE I
HIT NETWORK DESIGN OBJECTIVES

Frequency band	14/12 GHz band
Earth station antenna diameter	1 meter
Earth station transmitting power	1 watt
Outage	0.5%/year
Transmitting signal modes	Low bit rate information and still picture simultaneous transmisson
Communication system	PC-USAT system
Modulation technique	QPSK
Transmitting bit rate	64 kb/s
Transponder bandwidth	100 kHz
Interconnection between user	Optical fiber/ SHF band terrestrial wireless system

with rain attenuation, allowing the system to operate at a rain margin of several dB. In Fig. 5, the concept of the PC-USAT system is explained. The operating procedures are as follows:

1) In clear sky conditions, the large packet size (8192 bytes) is utilized,
2) In the case of heavy rain attenuation or traffic congestion, the link is discontinued. In this case, the ACK or NACK signals from the earth station, ES-2, are not received by ES-1. After a predetermined time, e.g., 10 seconds, the shortest size (32 bytes) packets are frequently transmitted by ES-1 until the ACK signal from ES-2 can be received.

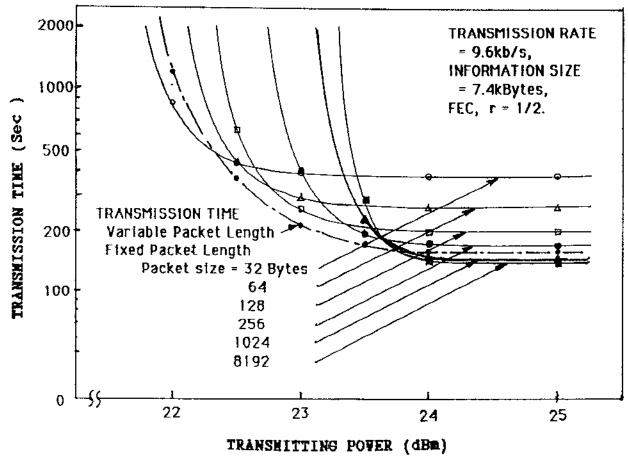

Fig. 6. Experimental results of transmitting power and transmission time for PC-USAT system.

3) When the ACK signal from ES-2 is returned solidly, then the packet sizes are increased and eventually increased to the maximum size when the disturbance stops.

C. HIT Network Design Objectives

Design objectives of the HIT network are summarized in the Table I. As shown in the design objectives, the PC-USAT system, small earth station and low bit rate information/still-picture simultaneous transmission techniques are adopted to achieve a low cost network.

IV. PC-USAT SYSTEM CHARACTERISTICS

To confirm these HIT network characteristics, a PC-USAT system experiment and propagation experiment were carried out using the JCSAT transponder.

A. PC-USAT System Experiment

Two kinds of PC-USAT system programs were examined: 1) fixed packet length and 2) variable packet length versions. The relationship between high power amplifier (HPA) transmitting power, which determine the C/N value, and transmission time with changing packet sizes are shown in Fig. 6. In this experiment, an earth station with a 1.8-m-diameter antenna and a 100-kHz bandwidth JCSAT transponder are used. The information size is 7.4 k/bytes. Forward error correction (FEC) (coding rate: $r = 1/2$) is also utilized. In the fixed packet length version, the packet sizes were changed manually by a control program from 32 bytes to 8192 bytes. On the other hand, in the variable packet length version, the packet length was changed adaptively in the PC-USAT system program depending on the C/N values.

From Fig. 6, the following can be deduced:

1) When the C/N value is sufficiently large, large packet size transmission time is less than that of small packet size, because of less transmission delay time effect.
2) When the C/N value becomes small, a large packet size signal can not achieve the throughput, since large error probabilities occur within one packet. In contrast,

a short packet size can achieve a good throughput for lower C/N values.
3) A variable packet length system (dash line) can reduce transmission time by as much as 1/3, compared to a fixed packet size.
4) When the C/N value becomes small, the variable packet length system can lower the required transmission power by as much as 1.5 dB below that required for the fixed packet size. By using this variable packet size system, only 2–3 dB rain margin is sufficient for error free communication, even though the delay time due to propagation attenuation or protocol procedures becomes longer.

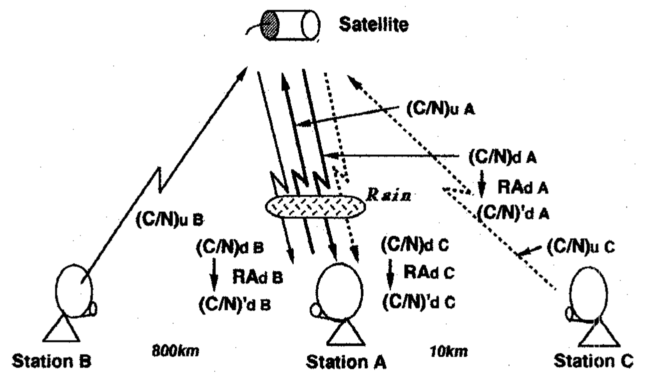

Fig. 7. Calculation model of rain attenuation and site diversity characteristics.

B. Propagation Data Experiments

1) Theory to Determine Rain and Snow Attenuation Values: By using the PC-USAT system, error-free communication can be realized with only several dB rain margin. However, it is necessary to know how availability can be achieved by this small rain margin. The calculation method proposed is based on receiving homogeneous QPSK signals from several earth stations and processing them in one receiving earth station. In this method, a long-distance earth station is used as a reference earth station. In Fig. 7, the earth station-A (ES-A) is the data processing earth station, and ES-B and C are the transmitting PSK signal earth stations. All experimental earth stations have homogeneous characteristics. Notations u and d mean up-link and down-link, and A, B, C mean earth station identification. In Fig. 7, the distance between A and B is sufficiently large to obtain good site diversity, e.g., 800 km, and distance between A and C is about 10 km.

2) Up- and Down-Link Rain Attenuations of ES-A: Two assumptions were used in the experiment:

1) Reference earth station (ES-B) does not suffer rain attenuation at the same time with earth stations A and C, because of sufficient large distance between the two earth stations, and
2) Every QPSK carrier has sufficient output power back-off, so the up-link signals are lineally amplified by the satellite transponder.

When rain attenuation occurred near the ES-A, this down-link attenuation is equal to the ES-B down-link attenuation. If the signal attenuation of ES-A and ES-B are defined as RA_{dA}, RA_{dB}, its values can be calculated by (1) and (2),

$$RA_{dA} = (C/N)_{dA} - (C/N)'_{dA} \quad \text{(dB)} \tag{1}$$
$$RA_{dB} = (C/N)_{dB} - (C/N)'_{dB} \quad \text{(dB)} \tag{2}$$

where $(C/N)_{dA}$ and $(C/N)_{dB}$ are clear sky down-link C/N values of the signal from ES-A and ES-B, and $(C/N)'_{dA}$ and $(C/N)'_{dB}$ are attenuated down-link C/N values for ES-A and ES-B.

Those down-link signal attenuation values concerned with the ES-A are same values, then

$$RA_{dA} = RA_{dB} \quad \text{(dB)}. \tag{3}$$

This means that the attenuation of the ES-B spectrum (which is measured by spectrum analyzer in the ES-A) is the down-link attenuation of the ES-A.

The two-way (up- and down-links) attenuation of the ES-A is measured by the total attenuation of the ES-A spectrum. Then,

$$\begin{aligned} &RA_{(u+d)A} \\ &\quad = \{(C/N)_{uA} - (C/N)'_{uA}\} + \{(C/N)_{dB} - (C/N)'_{dB}\} \\ &\quad = (RA_{uA} + RA_{dA}) \quad \text{(dB)} \end{aligned} \tag{4}$$

From (1)–(4), the up-link attenuation of ES-A. RA_{uA} can be introduced as follows

$$RA_{uA} = RA_{(u+d)A} - RA_{dA} = RA_{(u+d)A} - RA_{dB}. \tag{5}$$

This means that the up-link attenuation of the ES-A can be introduced by the attenuation spectrum difference between ES-B and ES-A.

3) Up-Link Attenuation of the ES-C: The rain attenuation of the link from the ES-C to the ES-A $RA_{(uC+dA)}$ can be expressed as (6)

$$\begin{aligned} &RA_{(uC+dA)} \\ &\quad = \{(C/N)_{uC} - (C/N)'_{uC}\} + \{(C/N)_{dA} - (C/N)'_{dA}\} \\ &\quad = RA_{uC} + RA_{dA}\text{(dB)}. \end{aligned} \tag{6}$$

Then, the up-link attenuation of the ES-C RA_{uC} can be determined by (7)

$$\begin{aligned} RA_{uC} &= RA_{(uC+dA)} - RA_{dA} \\ &= RA_{(uC+dA)} - RA_{dB} \quad \text{(dB)}. \end{aligned} \tag{7}$$

This means that the up-link attenuation of ES-C can be determined by the difference between the spectrums of ES-C and ES-B. By using the up-link attenuations of ES-A and ES-C, the site diversity characteristics can be obtained. In the proposed method, only one earth station can be evaluated for the site diversity characteristics.

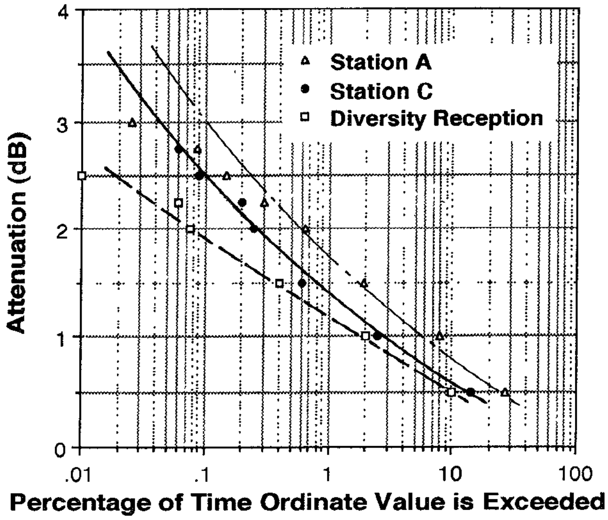

Fig. 8. Up-link rain attenuation and site diversity characteristics of ES-A and ES-C.

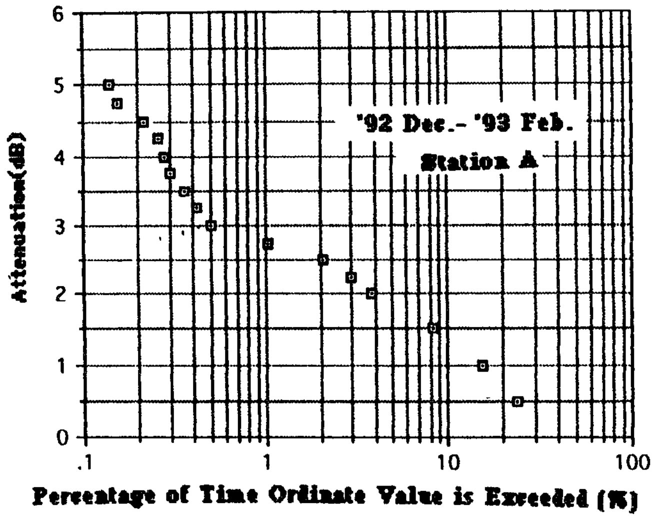

Fig. 9. Both (up and down) links snow attenuation characteristics of ES-A

C. Experimental Results via JCSAT

Rain Attenuation and Site Diversity Results: In Fig. 8, the rain attenuation of ES-A and ES-C and the up-link SD characteristics between the two stations are shown. From this figure, the following becomes clear:

1) Rain attenuation for the three months of summer of 1993 in the Sapporo area is relatively small, 2–3 dB for 0.1%/year,
2) Rain attenuation of ES-A and ES-C have some differences, although the distance is 10 km,
3) From the SD characteristics, the improvement factor of time probability by site diversity is about 1/10. A prior SD experiment is described in [12], which showed the result of 20 GHz band SD characteristics with 30-km distance. In this example, the improvement factor is about 1/16. The new result of 1/10 improvement factor for 10-km distance and 12-GHz band is an appropriate value.

Snow attenuation results: Signal attenuation characteristics due to snow have not been obtained, since it is difficult to separate propagation path attenuation and attenuation due to snow on antenna. In this experiment, a negative-gradient slanted polymer-shielded (NGS) antenna [13], [14] is used to prevent snow from sticking to the antenna. Fig. 9 shows snow both (up and down) links attenuation probability for the three months of winter. Compared with Figs. 8 and 9, the attenuation for rain or snow is almost the same. So, the system design must account for snow attenuation as well as rain attenuation.

System design consideration: From the results of rain and snow attenuation in the Sapporo area, if a 3-dB rain margin is selected in the PC-USAT system, the outage is 0.2%/year, about 16 hours/year. This value is a sufficiently small value for the specified service information transmission, where the real time transmission is not a system requirement. The problem caused by rain attenuation can be overcome by using a PC-USAT system.

From experimental results of the SD characteristics, introduction of a SD system not adequate for a system with only a small rain attenuation system, like the PC-USAT system. The SD system should be introduced for high bit rate information transmission system with large earth station antennas and large rain margins.

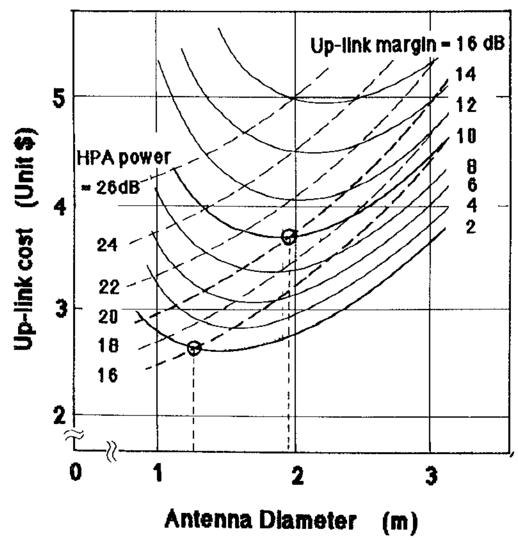

Fig. 10. Relation between up-link cost and antenna diameter.

V. Application Example

The PC-USAT system and rain attenuation example of a 12-GHz band can be verified from the above discussions. Those results can be applied to contribute to a minimum-cost HIT-network as follows.

A. Example of Cost Reduction Using the PC-USAT System

The up-link earth station cost is a total of the antenna cost and the high power amplifier (HPA) cost. There are many combinations of antenna diameter and HPA transmission power to obtain the required constant C/N values. In Fig. 10, the relation between the up-link cost and antenna diameter with the parameters of rain margin and transmission power are shown. In a conventional system design, a sufficiently

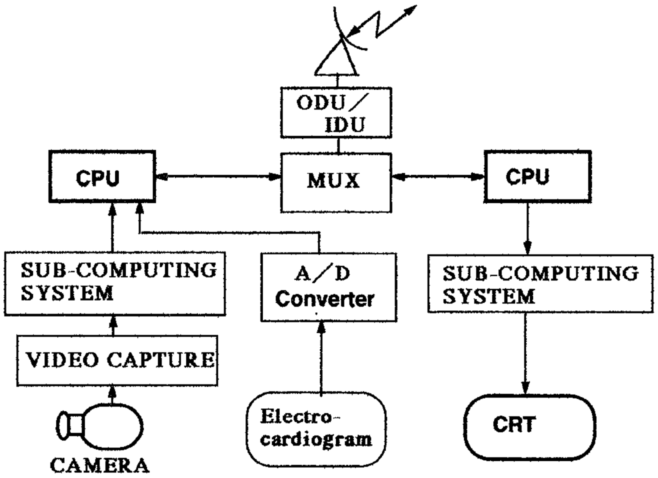

Fig. 11. Block diagram of simultaneous digital transmission of low bit rate medical information and still-picture.

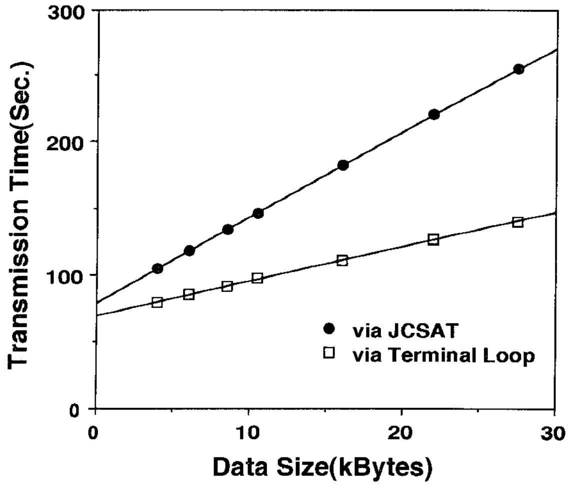

Fig. 12. Experimental results of simultaneous digital transmission.

large rain margin (e.g., 10 dB) is selected to compensate for rain attenuation. However, in the variable packet length PC-USAT system, a small rain margin (2–3 dB) will be sufficient. For example, the cost optimum (or minimum) point for a conventional VSAT system and PC-USAT system can be determined from Fig. 10. If a rain margin of 10 dB is assumed for a conventional VSAT system, then about a 2-m-diameter antenna will be required. On the contrary, if a 2-dB margin is selected for a PC-USAT system, only a 1-m-diameter antenna is required and 4 dB lower HPA transmitting power can be used.

From these results, a new concept of a low cost, easy maintenance USAT system for medical or educational information transmission can be realized, aiming the design objectives in Table I.

B. A Simultaneous Transmission System for Low Bit Rate Medical Information and Still-Picture

Need for Visual Medical Information: The fundamental medical information requires low bit rate information, e.g., electrocardiogram, temperature, blood pressure, pulse rate. However, transmission of visual medical information, e.g., CT scan image, X-ray photograph, open-wound picture, patient's face color, is valuable information for a doctor's medical judgement, even if the information is only still-pictures.

In a conventional medical transmission system, low bit rate medical information and visual medical information are transmitted separately. This means that two channels are necessary and, as a result, efficient utilization of the frequency spectrum cannot be achieved. Moreover, the cost of analog visual medical information equipment is expensive. And so, some resolutions must be considered in the HIT network.

Simultaneous digital transmission of low bit rate medical information and still-pictures can be achieved by the following candidate methods: 1) an all digital and multiplexing method, 2) a sequential transmission method of still-pictures and low bit rate medical information. In the HIT network, the latter method is adopted. In the latter method, low cost personal computer interface boards can be used.

A simultaneous digital transmission system block diagram is shown in Fig. 11. Visual medical information is taken by the camera and a YC (luminance and chrominance) signal is sent to the video capture board. This signal is converted to a red-green-blue (RGB) signal by personal computer and then compressed by the sub-computing system board. During the compressing procedure in the sub-computing system, the low bit rate medical information is converted to a digital signal by an A/D converter and stored in the buffer of the computer. After compression, the visual medical information is transmitted as a still-picture and then the low bit rate medical information is transmitted to the satellite link. At the receiving earth station, still-picture and low bit rate medical information are stored in the buffer of the computer and the visual medical information is expanded and displayed on the display tube of the medical center.

Simultaneous Digital Transmission System Experiment via JCSAT: The simultaneous digital transmission system program is combined with the PC-USAT system program. The experimental results are shown in Fig. 12. In this figure, the relation between the compressed information rates and transmission times are tested with a transmission bit rate of 9.6 kb/s and data size of 12.7 k/bytes. As shown in Fig. 12, the transmission times are 90 seconds for modem to modem, and 200 seconds for satellite to satellite transmission. The time differences between modem and satellite links occur due to the multiplexing and demultiplexing processing time in the multiplexer, and the packet delay between earth stations via satellite.

C. Other Applications of the HIT Network

The HIT network can be applied not only to medical information transmission but also to such things as: educational information, economics information, and LAN information transmission, etc. Also the concept of the HIT network has been applied to experiments of medical information transmission between ambulances and medical centers [15]. The PC-USAT system can be applied also to emergency uses for natural disasters.

VI. Conclusion

The PC-USAT system, which offers new low cost, high reliability system strategy for the HIT network, has been examined. By the variable packet length PC-USAT system, where the packet length is changed in accordance with rain attenuation, optimum packet lengths are selected automatically and shortened transmission times and lower C/N values operation has been achieved.

To design the optimum rain margin for the HIT network, propagation experiments were carried out. The 14/12-GHz-band rain and snow attenuation and SD characteristics were examined by using a one earth station measuring system. From rain and snow attenuation data, it has been verified that a system outage of 0.2%/year can be achieved by PC-USAT system.

The low bit rate medical information and still-picture simultaneous transmission system technique provides more medical judgement information for doctors with low cost terminal equipment construction. However, further study is needed to establish long time propagation data and to set up a well-established HIT network.

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