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# Asian Internet Interconnection Initiatives

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## 第1章 Introduction

Large number of technologies for the Internet have been developed and improved continuously since 1980's. The process of technology development and improvement always requires the network environment where engineers and researchers can make implementation, test, and evaluate the technologies. This network environment is so called "a testbed network." It is quite popular for the Internet community to provide testbed networks for specific technology development and deployment. Mbone for example, was set up and has been operated since early 1990's. The Mbone is a testbed network for IP multicast technology. The other example is 6bone which has been composed for IPv6 and operated since mid 1990's. These testbed networks can accelerate the process of technology development and its engineering, therefore, it is fairly important for research groups of Internet technologies to build and operate its testbed network.

The project discussed here in this article is an international research consortium among research institutes in Asian region and is aiming to form a group of researchers to develop leading edge technologies for the Internet, such as IPv6, WWW caching and replication mechanisms, multimedia communication mechanism and applications for the advanced usage of the Internet. The name of the project is Asian Internet Interconnection Initiatives[170, 169] or "$AI^3$" (ei-tripl-ai) in short.

This project was formed in 1995 by WIDE Project and started its activities in 1996 with its initial partners that are Institute of Technology in Bandung (ITB) in Indonesia, Asian Institute of Technology (AIT) in Thailand and Hong Kong University of Science and Technologies (HKUST) in Hong Kong. As its testbed network, Ku-band satellite communication channels have been used, therefore, each $AI^3$partner has been operating its Ku-band VSAT earth station and gateway systems to attach its local testbed environment to $AI^3$backbone. For the first three years of the project, all the members of this project worked hard to develop several technologies for the Internet, and the series of experiments utilizing this testbed backbone were conducted. The operation of our testbed network is a large-scale satellite Internet infrastructure. When our project was established, there was no other Internet infrastructure with satellite in the world. Hence, we had a good opportunity to develop several technologies that are vital for smooth operation of the satellite Internet infrastructure.

In 1999, $AI^3$project expanded its activities to more countries and added several C-band satellite channels to span these new partners as its new backbone network. The project invited 5 research institutes as its new partners: Temasek Polytechnic (TP) in Singapore, University Sains Malaysia (USM) in Malaysia, Advanced Science and Technology Institute (ASTI) in Philippines, Institute of Information Technology (IOIT) in Vietnam and University of Colombo (CMB) in Sri Lanka. Finally, $AI^3$testbed network has been expanded as shown in Figure 1.1. As of April 2001, IOIT finished to construct their earth station and waits for the initial uplink test to establish the link. CMB is in the process to procure the parts of their earth station along with the minimum requirement as described later.

In this report, we explain $AI^3$Project and detail of the $AI^3$testbed network. Furthermore, we report our sustainable efforts on research activities in Asia by using this testbed and evaluate the

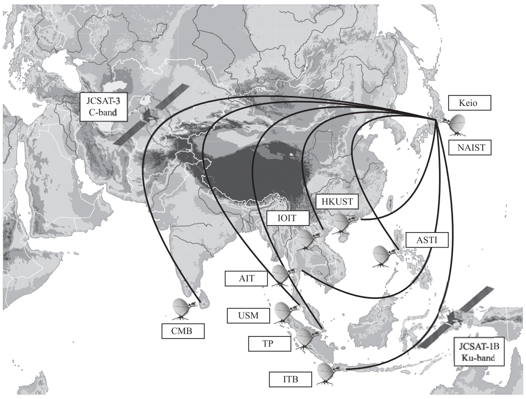


**Fig. 1.1**. Topology of AI$^3$Testbed Network

results about deployment of our satellite Internet technology.

# 第 2 章 Issues

## 2.1 Radio Frequency Band for Satellite Segment

In deployment of information infrastructure in Asian region, it is important for rapid development of infrastructure to adopt satellite communication technology. Satellite communication can be rapidly and directly established at any two points under its beam coverage and this characteristic is proper for Asia, because Asian region includes many highland and island nations where terrestrial communication infrastructure is currently not enough installed for the Internet.

As radio frequency band providing information rate in megabit class, Ku-band and C-band are available in Asia. Ku-band is permitted to use for satellite service that means fixed satellite communication service. However, Ku-band has a weakness against rain attenuation. In Asia, there are many areas which have heavy rainy season. On the other hand, C-band is much popular in Asia but some countries do not permit to use C-band for satellite service. C-band is affected by sun interference in equinox season. We need to select radio frequency band to be suitable for the purpose of deployment of information infrastructure in Asia.

## 2.2 Network Topology and Routing

The major issue about infrastructure is to realize that Asian countries can share scheme and expertise on the Internet development, especially on the intra-Asia internetworking. In the early phase of the Internet development, many countries and regions in Asia had direct connections to the United States and European countries, but there were less connections among Asian countries. However, as growing demands of cooperative works among Asian countries, it became popular to use the Internet as their ordinary communication channel.

As a result with this situation, many people complained about its large RTT (Round-Trip Time) and lack of bandwidth of the intra-Asia Internet connectivity, because few Internet links were installed between Asian countries. We need a network topology to be suitable for the intra-Asia communication.

## 2.3 Towards Sustainable International Collaboration

Our testbed network is expected to function as information infrastructure for acceleration of more cooperative works among people in and around the Internet in Asian countries.

In deployment of an international cooperative environment from Japan to Asian countries, the typical approach is on the donation basis. The donation approach may cause problems. This approach is easy to fall into one-sided “giver-receiver” relationship. The giver tends to put more emphasis on the supply and the equipment side, while the receiver needs to put more emphasis on technology transfer and collaboration in building the knowledge for long lasting and sustainable development. Therefore, this relationship causes the problems concerning no transfer of technical and expertise knowledge and no production of the environment fitted for the receiver’s surroundings in developing nations.

In AI$^3$project, it is important to establish partnership where technology transfer can be smoothly processed and partners can learn knowledge or experience from each other.

## 第3章 AI$^3$ Solutions

### 3.1 Radio Frequency Band for Satellite Segment

We divided our deployment process into two phases to establish satellite links among Asian countries as widely as possible. The first step was to use Ku-band. The next step was to use C-band, while holding the installed Ku-band links.

In the first phase, we challenged to use Ku-band in rainy Asian countries where heavy rainy season is existing. At the early period in this phase, many users in Asian countries such as Indonesia doubted availability of Ku-band links as Internet backbone. As a result of evaluation in the three years, we confirmed that Ku-band links using Asian zone beam are enough feasible as Internet links to satisfy the users in rainy Asian countries. In fact, more than 15 academic and research institutes have been using the Ku-band link for their backbone connection in Indonesia since the creation of AI$^3$project. Furthermore, we developed satellite Internet monitoring systems, so that we could clarify the fault point in this complex system. These systems contributed to exclude many troubles not associated with rain degradation while our link evaluation in Indonesia, Hong Kong and Thailand.

In the second phase, we expanded the use of radio frequency band to C-band. Our objectives were to verify our developed technology in C-band and to involve more AI$^3$partners from other Asian countries. As a result, we succeeded to establish IP connection using C-band with the sites located in Singapore, Malaysia and Philippines. To cope with sun interference, we started to share information about predictions of the interference among the partners.

### 3.2 Network Topology and Routing

We installed direct links among Asian countries in order to carry traffic for intra-Asian communication. First, we connected Indonesia, Hong Kong and Thailand with Japan by using Ku-band. Secondly, we also connected Singapore, Malaysia, Philippines with Japan by using C-band. Finally, we installed 10Mbps ATM terrestrial link between Ku-band and C-band networks, as illustrated in Figure 3.1. This ATM link was installed between the two hub stations in Japan to achieve IP routing among those countries via Japan. We have been field-testing OSPFv2 and BGP4 over satellite to exchange route information with each other and we confirmed that we can apply them in our intra-Asian satellite links.

RTT of our satellite link between Japan and the other country takes around 500ms. RTT of the ATM link needs about 30ms. Thus, we can estimate 500ms at minimum and 1030ms at maximum as RTT for our intra-Asian communication. Compared with IP routing via United States, RTT values are not much improved but are constant in any combination among us.

All intra-Asia links are of asymmetric nature based on the volume of information flow. Thus, each link was configured to 1.5Mbps from Japan and 512kbps to Japan, while this configuration is flexible to be allocated on the request basis under the permission of JSAT. The bandwidth of the ATM link is enough to carry traffic between

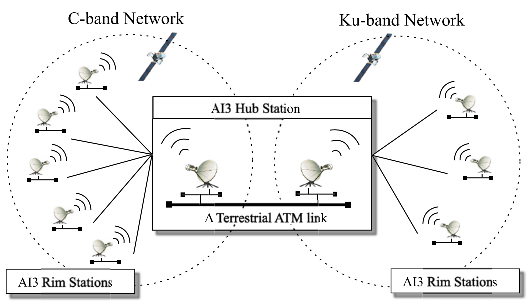


**Fig. 3.1**. AI$^3$Satellite Circuit

Ku-band and C-band networks.

### 3.3 Towards Sustainable International Collaboration

As stated earlier, technology transfer and equal partnership are important topics for international collaboration using our testbed. Before starting this project, we made a project framework about AI$^3$partnership. The framework defined that purchasing VSAT earth station, obtaining appropriate licenses from the local authorities and anything coordinated locally must be completed by each parter in each country. This allowed no exception including the sites in Japan. On the other hand, AI$^3$project provided satellite circuits (bandwidth on transponders) and related technical information to all the partners.

Within this framework, AI$^3$partners were invited from 8 Asian countries and we selected the groups who indeed needed AI$^3$project. The project members were on the equal partnership basis. Project related information was shared through the mailing list and the web among the members, though important issues such as bandwidth allocation of our satellite circuit were fixed after discussion at our regular meeting twice a year.

**Table 3.1**. Minimum Requirement for AI$^3$C-band Earth Station in case of Colombo in Sri Lanka

| | | | | |
|---|---|---|---|---|
| Satellite | | | | |
| | JCSAT-3 (128deg East) | | | |
| Frequency and Polarization | | | | |
| | JCSAT-3 C-band Frequency Range | | Uplink | 6225 - 6485 MHz |
| | | | Downlink | 3940 - 4200 MHz |
| | JCSAT-3 Conversion Frequency | | | 2285 MHz |
| | AI3 Assigned Transponder and Polarization | | | C-7 |
| | | | Uplink | 6365 +/- 18MHz (H) |
| | | | Downlink | 4080 +/- 18MHz (V) |
| Antenna Look Angles | | | | |
| | Azimuth | | | 97.5deg |
| | Elevation | | | 34.1deg |
| | Polarization | | | -56.7deg |
| Satellite Modem and Receiver | | | | |
| | Point to Point Modem between Hub and Rim Station | | | |
| | | Type | | SDM-300A |
| | | Manufacturer | | EFData - Adaptive Broadband |
| | | Required Option | | Variable Rate, Reed-Solomon Codec, Viterbi Decoding, 8PSK |
| | | Data Interface | (Interface) | EIA422 or EIA232 or V-35 |
| | | | (Connector) | 25, 37 or 50pin'D' or 36pin Winchester |
| | UDLR Receiver | | | TBA |
| Antenna and HPA | | | | |
| | Antenna Diameter | | | 4.5 m |
| | HPA Maximum Power | | | 10W for 512kbps (2/3 8PSK with RS) |
| | | | | 40W for 2048kbps (2/3 8PSK with RS) |
| | Required EIRP | | | 56.1dBW for 512kbps (2/3 8PSK with RS) |
| | | | | 62.2dBW for 2048kbps (2/3 8PSK with RS) |

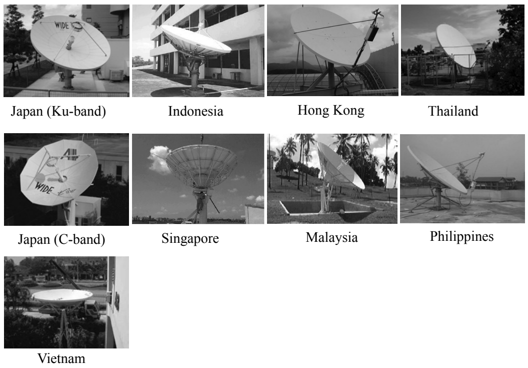


**Fig. 3.2**. AI$^3$Earth Stations Using the Different RF Units

In preparation process of the earth stations, AI$^3$project provided the information about minimum requirement of the station. An example of this minimum requirement in case of Sri Lanka is shown in Table 3.1. Along with such minimum requirement, AI$^3$partners set up their earth stations which were fitted for this requirement considering procurement, cost, maintenance and operation in their local circumstances.

Consequently, each earth station was set up using the different RF unit as shown in Figure 3.2. Through this process, we found that there were various regulations to start satellite communication in Asian countries. The required licenses from the local authorities were for wireless communication, location of earth station, import permissions of wireless devices and etc. Obtaining the licenses was much hard for AI$^3$partners in some cases, however, they finally accomplished this task in every way.

From the aspect of human resource development, AI$^3$partners got a complete *know-how* from the initial stage. Furthermore, a technical tutorial day was scheduled before the regular meeting twice a year and the leading-edge technologies were reviewed for AI$^3$partners.

## 第 4 章 Implementation and Evaluation

### 4.1 Satellite Link

Our satellite links use Ku-band and C-band provided by JCSAT satellite 1B and 3 respectively. Those types of emission are designed as listed in Table 4.1 and Table 4.3. The information rate of every link is asymmetric as described earlier. An example of each link budget is designed as shown in Table 4.2 and Table 4.4.

Ku-band has a characteristic of rain degradation, so we designed to keep the large number of clear sky margin. For example, between Japan to Indonesia in Table 4.1 clear sky margins are 8.8dB and 10.0dB. In order to apply the required C/N = 7.0dB, the modulation is QPSK with Viterbi FEC of 3/4.

On the other hand, C-band has less rain degradation, so small number of clear sky margin is enough, we designed C-band link's clear sky margin is lower than the Ku-band link's one. For example, between Japan to Singapore in Table 4.3 clear sky margins are 4.7dB and 5.4dB. For effective use of frequency bandwidth, 8PSK modulation was adapted. The FEC is the combination of sequential decoding and Reed-Solomon, but the required C/N is higher (8.7dB) than the one of Ku-band (7.0dB), because we give the priority to the effective use of frequency bandwidth.

In conclusion, our satellite links with these circuit designs have been enough stable to be used as Internet backbone in combination with Internet routing architecture such as BGP4 as described in the section 4.2.

**Table 4.1.** The Type of Emission in Ku-band Link

| | | |
|---|---|---|
| Satellite | | JCSAT−1B |
| Transponder | | K−3 |
| Information Rate | From Hub | 1.536 Mbps |
| | From Rim | 512 kbps |
| Moduration | | QPSK |
| Error Code | | R=3/4 |
| Required Eb/No | | 5.2 dB |
| Required C/N | | 7.0 dB |
| SFD | Japan | −88.0 dBW/m |
| | Indonesia | −87.4 dBW/m |
| Antenna Diameter | Japan | 3.6 m |
| | Indonesia | 3.6 m |

**Table 4.2.** An Example of Ku-band Link Budget

| Ku−band | | | Japan to Indonesia | Indonesia to Japan |
|---|---|---|---|---|
| UpLink | Earth Station EIRP | dB | 55.7 | 52.3 |
| | Uplink Path Loss | dB | 207.4 | 207.4 |
| | Satellite G/T | dBK | 2.8 | 1.6 |
| | Boltzmann Const | dB | 228.6 | 228.6 |
| | Bandwidth | dBHz | 60.1 | 55.3 |
| | Uplink C/N | dB | 19.6 | 24.4 |
| DownLink | Satellite EIRP | dB | 46.1 | 46.5 |
| | Output Backoff | dB | 16.5 | 21.1 |
| | Downlink Pass Loss | dB | 206.3 | 206.3 |
| | Earth Receiver G/T | dB | 26.3 | 26.3 |
| | Boltzmann Const | dB | 228.6 | 228.6 |
| | Bandwidth | dBHz | 60.1 | 55.3 |
| | Downlink C/N | dB | 18.2 | 18.7 |
| Total C/N | | dB | 15.8 | 17.7 |
| Required C/N | | dB | 7.0 | 7.0 |
| Clear Sky Margin | | dB | 8.8 | 10.0 |

**Table 4.3.** The Type of Emission in C-band Link

| | | |
|---|---|---|
| Satellite | | JCSAT−3 |
| Transponder | | C−7 |
| Information Rate | From Hub | 1.536 Mbps |
| | From Rim | 512 kbps |
| Moduration | | 8PSK |
| Error Code | | R=2/3, RS (225, 205) |
| Required Eb/No | | 6.1 dB |
| Required C/N | | 8.7 dB |
| SFD | Japan | −94.3 dBW/m |
| | Singapore | −94.5 dBW/m |
| Antenna Diameter | Japan | 7.6 m |
| | Singapore | 6.0 m |

**Table 4.4.** An Example of C-band Link Budget

| C−band | | | Japan to Singapore | Singapore to Japan |
|---|---|---|---|---|
| UpLink | Earth Station EIRP | dB | 50.5 | 45.5 |
| | Uplink Path Loss | dB | 200.6 | 200.6 |
| | Satellite G/T | dBK | 0 | 0.2 |
| | Boltzmann Const | dB | 228.6 | 228.6 |
| | Bandwidth | dBHz | 59.3 | 54.5 |
| | Uplink C/N | dB | 19.3 | 19.3 |
| DownLink | Satellite EIRP | dB | 39.2 | 38.2 |
| | Output Backoff | dB | 18.3 | 23.1 |
| | Downlink Pass Loss | dB | 196.7 | 196.7 |
| | Earth Receiver G/T | dB | 21.2 | 23.2 |
| | Boltzmann Const | dB | 228.6 | 228.6 |
| | Bandwidth | dBHz | 59.3 | 54.5 |
| | Downlink C/N | dB | 14.7 | 15.7 |
| Total C/N | | dB | 13.4 | 14.1 |
| Required C/N | | dB | 8.7 | 8.7 |
| Clear Sky Margin | | dB | 4.7 | 5.4 |

## 4.2 Network Topology and IP Routing

We describe the implementation and the evaluation of AI$^3$testbed network from the viewpoint of the international collaboration achieved in the past.

Our satellite circuit is a star shaped topology as shown in Figure 3.1, where all of the earth stations have capability of both data transmission and receiving. We implemented our TCP/IP network over the satellite circuit as illustrated in Figure 4.1. We use Cisco HDLC as the datalink protocol for each point to point IP connection. Routing information of the earth station networks is exchanged by using OSPFv2. BGP4 protocol is used for route exchange among AI$^3$partners. We have been using and evaluating these protocols over satellite since 1996. As a result, our link utilization shows that Internet backbone can be composed of Ku-band and C-band satellite links

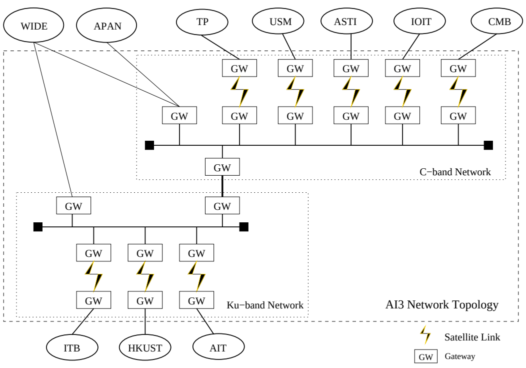


**Fig. 4.1**. AI$^3$TCP/IP Network Topology

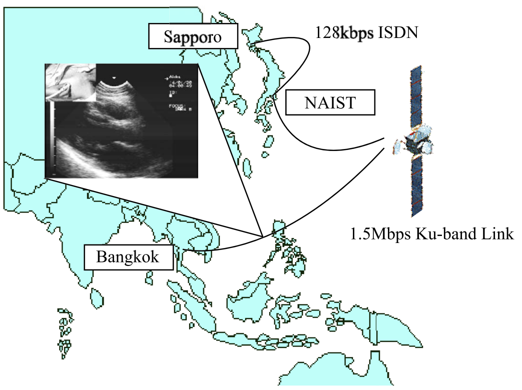


**Fig. 4.2**. A Real-time Telemedicine over Satellite

using Asian zone beam with the existing Internet routing technology in Southeast Asia. In particular we have confirmed that BGP4 over satellite in Ku-band links has been working enough to provide international backbone connectivity without parameter tuning and protocol enhancement in the five years.

In this way, AI$^3$project has been providing the testbed network to the users in and around AI$^3$partners. In fact, AI$^3$testbed network is helpful and sustainable for AI$^3$Indonesia group. More than 24 institutes in Indonesia have survived economic crisis in Asia by using this testbed as Internet backbone. Our link between Japan and Indonesia is still fully occupied by IP commodity traffic. Our network implementation being deployed in Asia is available and valuable for the use of backbone connection.

AI$^3$also has been improving its network connectivity and making collaboration in practice. AI$^3$is connected to both WIDE and APAN[26, 99] with 10Mbps ATM links. AI$^3$partners have chances of close collaboration with leading-edge research universities and institutions in United States and the other western countries using APAN TranPAC connected with STAR TAP[38].

For example, during the event of UNFCCC/COP3 in 1997 and UNFCCC/COP4 in 1998[171], AI$^3$testbed network performed a part to relay audio and video broadcasting from the conference hall to a large Internet audience in Asia. In addition, our testbed was used for real-time telemedicine experiments. A new telemedicine system which enables us to perform real-time remote diagnosis using a low bit rate medical image sequence up to 128kbps has been developed and was applied to our testbed in June 1999. This experiment verified that the proposed system provides real-time telemedicine environment over our testbed between Thailand and Japan[158]. The both test sites were connected as shown in Figure 4.2 through our testbed. The results implied that our testbed can contribute good accessibility to Asian researchers in the field of telemedicine[159].

In summary, even though our satellite links are long delay thin bandwidth Internet connection, it has been confirmed that our current topology and routing are enough valuable for international collaboration.

### 4.3 Network Management

Network management is quite important to keep its environment healthy. For this purpose, we are using an SNMP based network management system. With the system, we keep tracking all the status of routers, switches and other network devices and share this information among network operators and researchers in our project, in order to know fault point in the case links or gateway systems are down.

However, unlike the ordinary Internet system, we are using a satellite system for our backbone connections so that we also have to monitor satellite links. Stationary satellites are always monitored by link carrier's control center but those data are not opened online. Thus, earth stations remain as our target.

In generall electric devices consist of ODU and IDU in a VSAT earth station as illustrated in Figure 4.3. Data available around ODU are air temperature, precipitation and so on at the outdoor. IDU supplies Eb/N0 and AGC level fluctuation. Spectrum Analyzer for IF frequency at the hub stations provides changes of receiving signal power. Furthermore the serial interface attached to the gateway shows the link status, IP traffic volume, protocol distribution and etc. These four components are important to diagnose satellite link troubles such as no signal transmission.

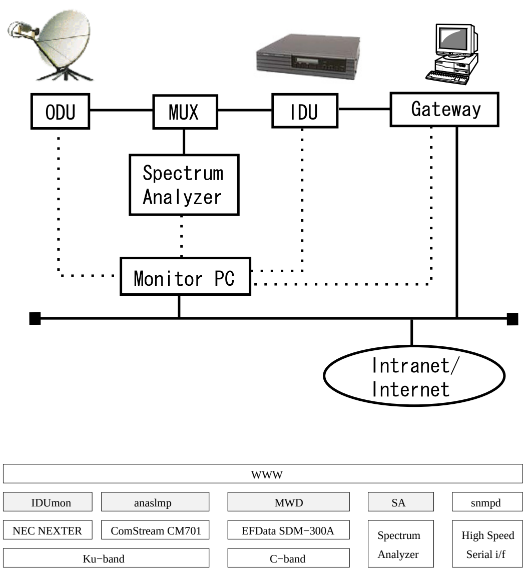


**Fig. 4.3**. AI$^3$VSAT Monitoring System

Weather condition around ODU sometimes affects satellite communication. For example, ODU tends to be exposed under high temperature in South Asia and it must be cooled down to work. A measuring device for temperature and a big external fan have been installed in Thailand since we found ODU over heated there. Rainfall and snowfall should be also measured. For example, ITB in Indonesia is running a weather station in order to detect heavy rains and record them with fluctuation of IDU status, since a heavy rain causes rain degradation against Ku-band links.

IDU status includes highly suggestive data to know dynamics of link condition from remote sites. In case of Ku-band, rain attenuation often causes a link to be unsynchronized and to be down during a heavy rain, when it drains a link margin. We can remotely know such link condition from IDU status. Statistical data recorded through a year brings us Ku-band link utilization in tropical regions. AI$^3$project has been using the three different IDU. We developed the three software products, IDUmon, anaslmp and MWD which can respectively monitor NEC NEXTER, ComStream CM701 and EFData SDM-300A as shown in Figure 4.3. An example of daily output by anaslmp is also shown in Figure 4.4.

Spectrum analyzer is useful in several senses.

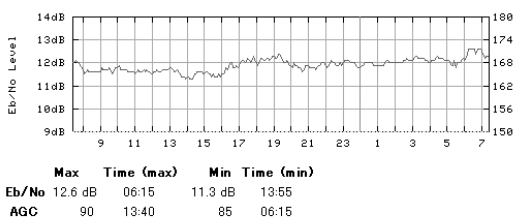


**Fig. 4.4**. A Daily Output of anaslmp

First, we can measure received signals at the hub station. It simplifies for operators to take a prompt action to check signals online. Secondly, it reveals performance debasement of communication devices integrated around ODU. In particular it is helpful at a complex earth station which has more devices such as TWT and downconverter in addition to ODU. In order to keep links up for IP connection, the serial interfaces attached with IDU on the gateways are also monitored.

In conclusion, we have collected statistical data helpful for the network management of the satellite Internet backbone, while operating our network with our systems.

### 4.4 Multicast Testbed

Our objectives to run Multicast testbed are to share Mbone experiences, to develop multicast applications and to reseach multicast technology using satellite.

We have been conducting the series of experiments with Mbone over our testbed since 1996. It is meaningful for Mbone beginners in the partners to acquire expertise about Mbone technology. For example, a historical event, Hong Kong Hand Over has been broadcasted through our Mbone testbed by HKUST AI$^3$group on July 1st in 1997. Through this event, AI$^3$members have learned some techniques such as use of scoped multicast address to transmit video streams with different rates for respective bounded networks. At NAIST earth station, 512 kbps Mbone session was received with video from 3 to 8 fps and lossless audio in 24 hours.

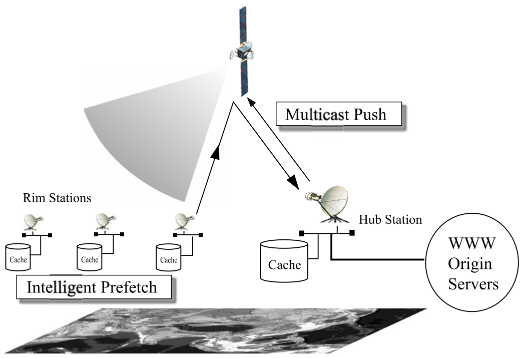


**Fig. 4.5**. AI$^3$Cache Bone

We have been making efforts to develop multicast applications. A hierarchical WWW cache using multicast over satellite has been proposed and developed for cache delivery. This system is called as AI$^3$Cache Bone with formation for providing both higher hit rates and saving the overall bandwidth consumption through fetching WWW objects and multicasting them over satellite[78, 79]. Figure 4.5 shows a basic model of AI$^3$Cache Bone. In Asian region, we confirmed that the performance of our rim cache is much improved by approximately three folds when compared with an ordinary hierarchical cache system such as Squid. We have finished all the implementation of the adaptive cache including the multicast push caching. The average of the hit rate observed at AIT cache was above 50%[152].

## 第 5 章 Discussion

We in turn installed the Ku-band and C-band networks to deploy our testbed network in Asia. Pioneer use of Ku-band links explored possibility for the application to Internet links. Development of C-band links contributed to increase our link coverage in Asian region.

Using these networks, further collaboration is expected with new invited AI$^3$partners such as in Vietnam or Sri Lanka. For example, in Vietnam AI3-Vietnam was implemented involving around 17 universities and research institutes in Hanoi where AI$^3$earth station is located. AI3-Vietnam is a framework for Vietnamese researchers to collaborate together on AI$^3$project. The southern universities and research institutes will join them likewise as soon as their backbone link between Hanoi and Ho Chi Minh City is improved enough. The situation is similar in Indonesia, Philippine and Sri Lanka. In this way AI$^3$project accelerates opportunity for intra-Asia collaboration.

Although all the satellite links in our testbed network are currently configured as bi-directional, we are planning to add unidirectional links in our testbed. With those links, we are going to work research on integration between point-to-point and point-to-multipoint satellite links to function well as satellite based network infrastructure.

For instance, we are going to develop a new routing mechanism working with unidirectional link routing[40]. This link integration technique is useful to control satellite link bandwidth in response to temporal increases of one way traffic. Also it can be shared among multiple sites to receive Internet application traffic such as Web cache injection and replications, content mirroring and etc. Developments of core technologies to enable us to configure this kind of unidirectional link is undertaken. With bandwidth available in our C-band channels, we are going to conduct experiments of this unidirectional link technologies with our partners.

The other research goal related to this unidirectional link is to develop applications for receive only site. Research and development on distant learning have become active in Asia[112][93]. However, in some areas in Asia, there is still no communication infrastructure including stable telephone lines, but there is heavy demand to feed up-to-date information for people living in such area, especially for education purposes. Making "receive-only" satellite earth station is inexpensive and normally not required to obtain appropriate license from authorities. With this kind of "receive-only" terminals, we are going to make on-demand data feed mechanism on the unidirectional links.

IPv6 is a key technologies for the Internet next generation. In the AI$^3$testbed network, 6bone-AI$^3$ is in operation and it is connected with 6bone. We gradually expand IPv6 experimental networks to Asian countries through our testbed. In fact, our deployment efforts accelerate each IPv6 promotion and regional deployment in Asian countries such as Indonesia, Philippine and Malaysia. In Malaysia, there is a multimedia conferencing system called MCS[130] developed by AI$^3$Malaysia group and they started to work for enabling MCS to run as one of IPv6 applications[145].

Now that we confirmed worth of Ku-band and C-band links as described earlier, let us consider Ka-band links. Ka-band is worse affected than Ku-band against rain attenuation but Ka-band brings faster link performance upto the Gigabit order. As a result of this link property, we face a problem that is less utilization of Ka-band links in rainy region. However, in redundant implementation, other bands and/or terrestrial lines can automatically backup Ka-band links by means of Internet routing technology as well as Ku-band.

## 第6章 Conclusion

We've been running AI$^3$project for these five years. During this period, many international collaborations have been produced and our testbed has been used for the purposes of experiments in the process of technology development and deployment.

For application technology development, our project enables researchers to develop advanced Web caching mechanism and to achieve the international telemedicine experiment. For Internet development, AI$^3$project verified feasibility of the use of Ku-band satellite links in tropical region in Asia. This result accelerated satellite operators to provide Ku-band transponders which covers Asian countries.

AI$^3$project also has helped sustainable development of human resources. We can find a notable case study from our experiences in Indonesia. Because AI$^3$testbed network has survived even in economics crisis in Indonesia, ITB has been taking a leading part in this human resource development in Indonesia with many mailing lists. Now the number of mail delivery on their server has grown to send more than 70,000 mails every day to Internet community in the country. AI$^3$project is expected in the other Asian countries such as Vietnam to accelerate their research and development activities focused on Internet technologies.

AI$^3$project has provided our efforts to make international collaboration since 1996. As a part of APII[9] testbed and also as a part of APAN, our testbed is continuously expected to work as a network infrastructure interconnecting among Asian countries for academic and research purposes.