Overview of AI3 Network: Design and Applications of Satellite Network

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ABSTRACT

Many developing countries are not gaining benefits from the Internet as the network infrastructure has not yet been built due to the economic or administrative restrictions of these regions. Asian Internet Interconnection Initiatives (AI^3) has been developing a research consortium of 29 partner institutions in 13 countries utilizing an Internet infrastructure over a satellite links. The project aims to develop partnerships and human networks to foster researchers within the regions to carry out research on the satellite Internet and to develop their regions. We have successfully conducted productive research and also developed a distance-learning environment as a result of more than a decade of experiments. This paper aims to share the operational know-how and results of research from AI^3's activities to construct a network and applications that would support developing regions.

1. INTRODUCTION

The Internet is an infrastructure to support various social activities, such as business, commerce, education, and researches. However, some countries in Asia are defined as developing and stable high-speed Internet infrastructures cannot be developed in the short term due to their economic or administrative restrictions. We believe that the infrastructure of the Internet is one of the keys for developing countries to accelerate the development.

Asian Internet Interconnection Initiatives (AI^3) is an international research consortium of 29 organizations in 13 Asian countries as shown in Figure 1. AI^3 began in 1995 aiming to carry out research and construct an educational infrastructure through developing a digital-communication infrastructure on satellite links [1] [2] [3]. Since then, we have been trying to create strong partnerships among in the region through the practical operation of our network and cooperative research activities. Our partners include Japan, Indonesia, the Philippines, Singapore, Vietnam, Malaysia, Thailand, Cambodia, Laos, Nepal, Myanmar, Bangladesh, and Mongolia. We aim to contribute to developing a communications infrastructure as well as human resources in these regions through the project.

Figure 1: AI^3 partners

We aim to introduce AI^3's over a decade of AI^3's experiments in this paper, where we have deployed and operated a digital-communication infrastructure using satellite communications, and achieved collaborative research that has been conducted using the infrastructure. This paper is expected to be a reference for future approaches to similar region-wide developments of infrastructures, network operations, and research utilizing satellite links.

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2. DESIGN OF AI^3 NETWORK

2.1 Geographical constraints and requirements

Asia occupies an extensive landmass and the geographic characteristics of the countries within it differ. While many countries in Asia are surrounded by sea, some of them are land-locked. The Asian region does not currently have a backbone network connecting all these countries and the present terrestrial links, occasionally using dial-up connections, are insufficient to accelerate Asia's development. It may take a long time to install fiber optics throughout Asia to develop a digital-communication infrastructure as the countries there have diverse economic or administrative restrictions.

2.2 Characteristics of Satellite Communication

Satellite links can be installed more quickly than terrestrial networks because; 1) the infrastructure can be developed independent of geographic features such as mountainous or isolated islands as long as the satellite signals reach them, 2) They can also be deployed independent of the existing terrestrial infrastructure because the satellite equipment can be carried around and located anywhere. 3) A satellite could cover Asia because a geostationary satellite can theoretically cover a third of the world. Another major characteristic is that satellites can simultaneously broadcast a single copy of data to multiple destinations.

However, we should also take other characteristics such as limited-spectrum resources, and fixed and long delays into consideration. Since the frequency bandwidth is a limited resource for satellites, its unit price is expensive. Transmitting signals on satellite links necessitates long delays because of constraints imposed by the speed of light.

2.3 Design Principle

We attempted to take advantage of the features of satellites to develop a digital infrastructure that would cover a wide area without geographical restrictions. We hence developed our infrastructure using satellite links.

We wanted all partner sites in the regions that participated in designing and implementing the Internet infrastructure to have equal responsibilities, motivations, and opportunities in its construction. We therefore designed our network to be an international Internet eXchange (IX) in Asia, where respective partners connected to the network worked as an autonomous system. We located the hub Gateway station in Japan.

3. EVOLUTION OF SATELLITE INTERNET

AI^3's satellite Internet has been evolving in three stages over the last decade. The design of the satellite Internet is changing as the satellite and Internet technology continues to evolve. AI^3 has always tried to integrate cutting-edge technology to lead research in the satellite-Internet field. Here, we will describe the three stages in the evolution of our satellite Internet.

3.1 Stage 1: Ku-band Link at the beginning

We have been developing the satellite Internet using the Ku-band since 1996 with support from JSAT, which is a communications carrier in Japan. The satellite hub station was constructed at the NAra Institute of Science and Technology (NAIST) in Japan. We also installed the earth station at NAIST. The Asian Institute of Technology (AIT) in Thailand, the Institut Teknologi Bandung (ITB) in Indonesia, and the Hong Kong University of Science and Technology (HKUST) in China are connected to the AI^3 network via the station. These sites are connected point-to-point to NAIST with a "Star Topology" and we succeeded in providing Internet connectivity to the distributed sites.

AI^3 obtained Autonomous System (AS) number 4717. The AS network was connected to WIDE (AS# 2500) and provided international transit communication from Japan to partner sites via the network. It allowed partners to determine their own routing control policies on the Border Gateway Protocol (BGP). Partners could control both satellite-link and terrestrial-link operations based on the AI^3 principle.

3.2 Stage 2: C-band Link Extension

We started to employ additional C-band communication in the second stage because we could obtain a wider bandwidth. It also gave us more stable connections against the frequent rain attenuations there are in Asian weather than were possible with Ku-band characteristics. We prepared new satellite equipment that could handle C-band communication.

A C-band earth station was constructed at Keio University, Shonan Fujisawa Campus (SFC) in Japan. AI^3's new partners, i.e., the Temasek Polytechnic (TP) in Singapore, the University of Science Malaysia (USM), the Advanced Science and Technology Institute (ASTI) in Philippines, and the Institute of Information Technology (IOIT) in Vietnam joined the project at that time to connect to the new C-band network

The Ku-band network was operated simultaneously with C-band operations. These two hub stations at NAIST and SFC were connected using a 10-Mbps terrestrial link. We could diversify the risks of failure by having two independent hub earth stations. This improved network sustainability even if critical situations occurred in Japan.

We have recently started to use Uni-Directional Link (UDL) technology on C-band links. UDL allows us to use satellite links as broadcasting media. In contrast to bi-directional communication, IP communication using UDL enabled a satellite one-way link and a terrestrial link that could be a narrow bandwidth to be combined. The UDL works as broadcast media like the Ethernet. The UDL Receiver only accepts packets when their destination belongs to the receiver. This mechanism is similar in the Ethernet environment. Therefore, a UDL is shared by sites that are connected to it.

3.3 Stage 3: Participation of RO Sites

The School on the Internet Asia (SOI Asia) was launched in 2001 [4] [5]. SOI Asia is a research consortium to support educational activities in the region as an application of the AI^3 network. AI^3 gained broadcast capabilities to all satellite-receiving nodes in its network through the successful development of UDL technology, This feature enabled us to simultaneously distribute lecture video and audio to all partner sites.

New partners joined the project after SOI Asia started activities, and they connected to the Internet by UDL on the AI^3 network. They received Internet traffic, especially that for educational programs, from UDL connections. Since

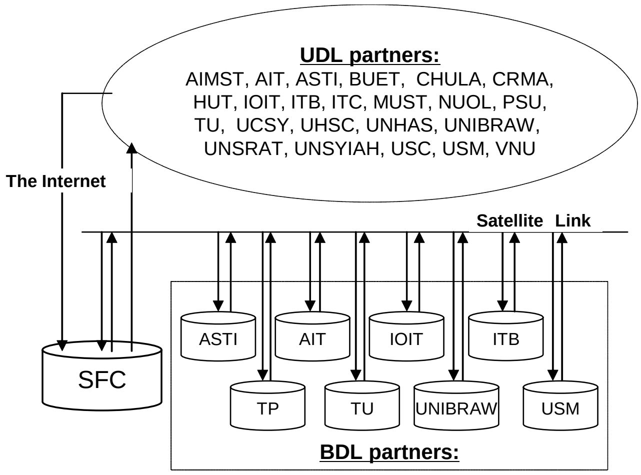

Figure 2: AI^3 satellite topology

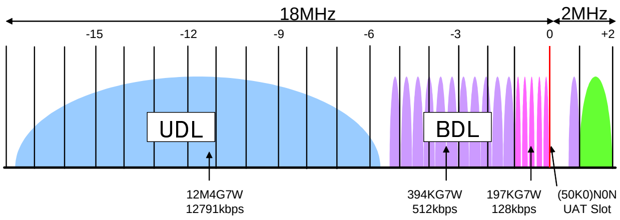

Figure 3: Radio wave frequency allocation

the UDL partners can not send any packets on the UDL connection, they use existing terrestrial infrastructures such as dial-up connections as return link. UDL Routing (UDLR) technology, which emulates a bi-directional asymmetric link over a combination of different links, allowed them to use the asymmetric connections. They are called Receive Only (RO) sites from their use of satellite links, SOI Asia partners are interested more in sharing educational resources and less in carrying out research on the satellite Internet. Hence, the AI^3 network characteristics changed to accommodate a more stable infrastructure for lecture video and audio streaming at lower operational cost. The AI^3 network currently has eight bi-directional partners and 28 unidirectional partners over C-band links.

Figure 2 shows the satellite-network topology. The earth station at SFC transmits signals between BDL partners and to UDL partners. The UDL frequency can simultaneously transmit aggregated traffic to many partners. Figure 3 represents the allocated frequencies in the current AI^3 network. We divided available frequencies into BDL and UDL. Satellite links are shared by both BDL and UDL signal transmissions. Finally, we reserved a wide bandwidth for UDL because it is one of the most effective ways of sharing limited radio-wave resources on a satellite link.

4. APPROACHES TO OPERATIONAL FACTORS

4.1 Link Technology

An exclusive frequency channel is ordinarily reserved for receiving signals from respective stations in satellite communication. When a station sends a signal to the satellite with the correct direction at an appropriate frequency and modulation setting, the satellite broadcasts the signal over the area covered by its communication. The other stations then receive the reflected signal.

Our approach was to use the satellite link to transmit data packets. We prepared the facilities for satellite communication which were an antenna, an Out-Door Unit (ODU), and an In-Door Unite (IDU). The antenna and ODU were used to transmit signals from/to the satellite. The IDU, which is also known as a modem, modulated data transmitted from a connected computer. The modem was equipped with an RS422C interface enabling it to be connected to an external data source. We connected the modem to a Personal Computer (PC) via the attached external RS422C interface board in early configuration. However, the RS422C external board on the PC-UNIX was not stable because the driver software was no longer being updated. Consequently, we started to use a hardware router to directly convert the data signal from the Ethernet to the serial line. The hardware router was equipped with RS422C interfaces on the extension slot. It provided a stable converting function instead of the PC router.

4.2 Bandwidth Utilization

The available bandwidth was determined in proportion to the frequency bandwidth.The available bandwidth on satellite communication was in great demand since the frequency bandwidth was a limited resource. AI^3 tried various techniques and technologies to enable the bandwidth to be effectively used by allocating frequencies, caching Web documents, and aggregating traffic by UDL.

The Utilizable frequency was determined by allocating frequencies in satellite communication. The BDL circuit uses an exclusive frequency, and allocating equal frequencies to all partners would have decreased the efficiency of utilization as the partners would not have used the bandwidth equally. Allocation of Frequency based on the partner's current use of bandwidth would thus maximize how effectively bandwidth was used.

AI^3 therefore monitors the use of bandwidth at partner sites, and allocates frequencies accordingly. As changes in the allocation of frequencies affect all partner sites, AI^3 facilitates consensus building at bi-annual meetings, which will be described in detail in a later section.

4.3 Monitoring

AI^3's satellite network is functioning as a transit AS of partner sites, and any kind of failure in the network will cause serious problems in their sites. Therefore, AI^3 is monitoring the network to confirm the healthiness of the network. Targets being monitored include services such as the Web, e-mail, and the Domain Name Service (DNS). Other targets are network conditions such as utilizable bandwidth and routing information, and link conditions such as the attenuation of satellite signals and the failure of satellite modems.

4.3.1 Service status

AI^3 operates http and mail servers in the network to disclose and share information. Sound operation of these services will support project activities. AI^3 employs various open-source softwares to monitor these services. Nagios is monitoring servers that are providing services such as DNS, e-mail and http [6]. However, since Nagios' monitoring function relies on network and link conditions, problems have to be analyzed taking all factors into consideration. The results of Nagios monitoring service can only be trusted when the network and links are working well. Version checks of software like ssh are also done regularly for security purposes.

4.3.2 *Network status*

The satellite network needs stable operation to maintain the infrastructure for our collaborative projects. The network can be monitored by utilizing existing technologies because the network layer is different to the link layer, where the satellite link is. Nagios can confirm whether the network can be reached, and AI^3 employs Nagios to monitor part of the network. AI^3 also uses a small script developed by one of the operator to report mailing lists of routing information to enable the network conditions to be checked. This script refers to the BGP router's routing table inside the AI^3's satellite network, which sends a summary to a mailing list. The AI^3 network works as an international transit IX, and these kinds of confirmation of routing information are very important.

4.3.3 *Link status*

Satellite links are in a lower layer than the network and applications, and failure on a satellite link will affect all the network and services that are running ontop of the link. It is therefore very important to recognize the satellite to identify the problem. Utilizing satellite links requires various hardware such as a communication satellite, an antenna to transmit/receive the radio-waves, and a satellite modem. This hardware has to work correctly to transmit and receive the waves to utilize satellite links. The satellite modem within this hardware can easily be checked as to whether it is working properly or not. The other hardware such as the communication satellite and antennas are continuously monitored by a satellite-communication vendor. Problems rarely occur in the satellite-link layer as the requirements for satellite equipment are very stringent by they do occur in higher layers. Although the possibility of these problems occurring is low, we have still experienced problems such as misalignment in the antenna due to blackouts and weather conditions, and deterioration of the equipment due to age. Monitoring the satellite links is also very important. The satellite-communication vendor continuously checks the reception of the satellite signal and partners can check for malfunctioning antennas or modems by contacting the vendor.

4.4 Security

We control accesses to servers and routers by filtering packets. Attacks against network equipment are prevented by prohibiting direct access to servers and routers. Access to the routers and servers inside the network first requires a remote login to a representative server. As any access inside the network relies on ssh, we try to keep it up to date by regularly checking versions of all machine ssh's. The service segment and commodity network are in different network segments, and packet filtering is employed to protect the core network.

4.5 Maintenance Operation

The operation of a satellite network requires the use of various equipment. Repairing it and finding substitutes is necessary when hardware failure occurs. Satellite equipment transmits data, and all countries have different legal regulations for communication by transmitting radio-waves. The satellite equipment in AI^3 is basically handled by Japanese staff with support from JSAT. When a satellite link suffers from some kind of trouble, the trouble is reported to Japanese operators using mailing lists, and plans for troubleshooting are discussed on an e-mail basis. AI^3 has tried to accumulate the know-how to solve problems by sharing the maintenance information within the group,

When hardware needs to be repaired, or substitute equipment is required, we ship the parts or hardware. Satellite equipment is occasionally considered too expensive to import when high customs duties are levied. AI^3 has been avoiding these kinds of problems by all institutions at all sites submitting a certificate to customs that states the equipment to be received will not be used for profit, but solely for research.

AI^3 is now trying to arrange the dispatch of satellite-related equipment for maintenance to partner institutions. The Japanese operators prepare a list of authorized satellite equipment, and their partners choose their own equipment to purchase and maintain based on the list.

4.6 Remote Maintenance

The AI^3 network consists of layer-3 network equipment such as routers and servers, layer-2 linkage equipment such as satellite modems and bridges, and layer-1 physical equipment such as antennas and cables. We use remote login software like ssh to maintain the layer 3 equipment remotely. We connect a PC server to layer-2 equipment using a serial console and connect it to the PC remotely to maintain this equipment.

4.7 Organization

AI^3 is an international consortium of many universities from various countries. Communication between partner institutions is indispensable to maintain and expand the project. As all the partners share the limited resources of the satellite circuit, so we need to agree on consensus to manage these and address conflicting requirements. It is important to share problems, provide countermeasures against them, and distribute research and results.

AI^3 mainly uses e-mail to communicate with the group. Asynchronous and public communication through e-mail is very effective for sharing information as its partners are in remote locations. The group's accumulated know-how and operational information are archived on the Web server. These are also used for publicity.

Online communication addresses most of the issues raised by the group. However, as the partner institutions are located in different locations with differing organizational formats and infrastructures, partner institutions do not always reach a consensus over e-mail-based communications, or this form of communication occasionally does not function. To avoid these kinds of problems, AI^3 holds bi-annual face-to-face meetings. Important topics are proposed and future directions are determined at these meetings to bootstrap online communications. These meetings are also used to share research ideas and results to accelerate joint projects by the group. This bi-annual three-day meeting is used to arrive at consensus and motivate the group for future development.

5. ACHIEVEMENTS FROM AI^3 ACTIVITIES

5.1 Standardization of UDLR Technology

AI^3 designed a unidirectional link on its network to become a test-bed for the Unidirectional Link Routing (UDLR) technology in 1999. One of the goals was to do research in integrating point-to-point and point-to-multipoint satellite links as a satellite-based network infrastructure. As a result of our research, our members proposed a UDLR standard draft to IETF UDLR WG. The proposal was accepted and published in RFC 3307 [7]. This technique of integration is useful for controlling satellite-link bandwidths in response to temporal increases in one-way traffic. Another goal was to develop applications for RO sites using an on-demand data-feed mechanism on unidirectional links.

Operation of the AI^3's unidirectional links began in 2001 and since then they have provided the network infrastructure for the SOI Asia Project and various experiments, such as multicast, and policy-routing. AI^3 is running a 13-Mbps unidirectional link, which doubles the capacity of the bandwidth for the original test-bed, which was 6-Mbps.

5.2 Distance Learning

SOI Asia has been developing an active distance-learning environment since 2001, utilizing the AI^3's satellite network as part of its infrastructure to share educational resources among the region. SOI Asia focuses not only on developing networks and applications, but also on developing human resources to operate the environment and design an operational framework for sharing educational resources on a committee basis. SOI Asia is employing state-of-the-art technologies to motivate and develop local operators with support from AI^3 partners, which they believe is the key to sustaining the technological environments in developing countries. SOI Asia had 28 partner educational institutions in 12 countries as of April 2006. SOI Asia has conducted 21 graduate-school-level courses (about 200 lectures) since its six years of experience, and more than 70 real-time sessions involving special seminars, and conference broadcasts.

5.3 Human Resource Development

AI^3 has attempted to develop equal partnerships between Asian universities to contribute to researcher growth in the region. The design of the satellite network is operated through discussion and agreement by the group based on this policy. Strong partnerships were formed in our project by continuing this process, The partnerships also contributed to successful development of human resources through operator workshops [8] and student and researcher exchanges by the partner universities. This development of human resources by the group is one of the purpose of our project, and we have successfully developed networks of researchers at our partner institutions. The human networks have contributed to operations, research, and educational activities by the group, and have accelerated their collaborative efforts.

5.4 Web Cache backbone on Satellite Internet

The AI^3 satellite network transmits various data from partner sites. We conducted research on Web caches in the satellite network [9] to decrease redundant data from its http traffic..

AI^3 developed a network of Web-cache servers, called the AI^3 Cache Bone, from the early phases of AI^3 to 2000 [10]. It is a hierarchical network of web cache servers designed based on the star-shaped topology of the AI^3 satellite network. The AI^3 Cache Bone consisted of a hub cache, which was located at NAIST, and rim caches located at the AI^3 partner sites.

The rim caches in the AI^3 Cache Bone used an intelligent prefetch mechanism, where the rim caches analyzed users' access patterns to generate a list of frequently accessed URLs that should be prefetched. This strategy of prefetching a rim cache was based on the statistical analysis of user-access patterns. Traffic was monitored to control both the prefetching and pushing of object operations. The AI^3 Cache Bone introduced multicast transmission to distribute the prefetch WWW objects from the hub cache to rim caches to reduce the consumption of satellite bandwidth. This mechanism proved that it could provide more than a 50% Web-cache hit rate at the rim cache at AIT.

5.5 Botnet Detection on Satellite Internet

A network of PCs that is taken over by a malicious program is called a botnet, and attacks by botnets are becoming serious threats. We conducted research to automatically detect botnet traffic using the AI^3 network [11]. The research attempted to detect the botnet traffic by monitoring the traffic patterns of data transmitted on AI^3's satellite network at Keio SFC, where the satellite hub station was located, and all the data was aggregated. Traffic from many regions in Asia can be monitored by the AI^3 network. Akiyama et al. described some indicators for automatically detecting botnets, and successfully detected several with these. We believe that the global-transit characteristics of the AI^3 network enable botnets to be effectively monitored as their activities occur extensively in networks. This is one of example pf the application of research to use the AI^3 network as a testbed to effectively use its characteristics. The AI^3 network is beginning to be used as a research infrastructure as it matures.

6. CONCLUSION

We started the AI^3 project to take advantage of the infrastructure of the Internet and to accelerate its development in the Asian region, AI^3 aims to contribute to the development of regional network infrastructures as well as the development of human resources in the region. Since then, we have been creating strong partnerships that have equal responsibilities, opportunities, and motivations.

We decided to employ the Internet infrastructure over satellite links because of its capabilities. AI^3 has been introducing new technologies to lead the researches on the satellite Internet along with the evolving Internet and satellite technologies. We used the Ku-band and C-band in the past decade to develop our network, and many operational tips and a lot of know-how were accumulated. AI^3 has standardized UDL technology, developed a region-wide distance-learning environment, developed human resources among the group, developed a Web cache backbone in the network, and conducted research on detecting botnets using our network as a testbed. AI^3 wishes to continue its research in various areas to strengthen the partnerships and develop more human resources in the region.

Although terrestrial links are expanding to areas that remain uncovered, there are still rural areas where the Internet is difficult to access. People have also recently been paying attention to communication services in emergency situations; earthquakes are the most typical.

Communication using satellite links are more expensive than that with terrestrial links. However,in developing countries and disaster-stricken areas, people think the lack of Internet connections is a present priority that should immediately be addressed. Preparing terrestrial links for such locations would be prohibitively expensive . Under these circumstances, satellite communication represents a promising technology to provide the communication services.

We are currently conducting research on IP-broadcasting technology for satellite communication. The technology is being developed based on research such as UDLR and IP multicast. We succeeded in broadcasting educational programs on our satellite network with SOI Asia project. Broadcasting in satellite communication uses spectrum resources efficiently because it allows the transmitted signals to be shared with multiple earth stations. This should contribute to reducing the high cost of satellite communication. We believe communication through broadcasting is a new kind of application for satellite communication not only in developing regions but also in advanced nations. We will continue to research IP-broadcasting technology and applications in the future.

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