Architecture of Satellite Internet for Asia-wide Digital Communications

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Abstract. This paper describes the network architecture of an Asia-wide satellite Internet that considers the situations in developing regions. The design considerations for the architecture are costs, effective use of satellite bandwidth, scalability, and routing strategy when combined with terrestrial links. The architecture includes using one-way shared satellite links to reduce costs, IP multicast to leverage the broadcast nature of satellite links, QoS, audio-video application gateway to adapt to the limited bandwidth of satellite links. This architecture is implemented in an operational network testbed connecting 13 countries and supporting a distance learning project.

1 Introduction

1.1 Background and Focus of Research

There are high demands for wide-area Information Communication Technology (ICT) infrastructure in Asia. Human resource development, closing the gap of the digital divide, and communications in emergency situations are among the driver for these demands. Broadband Internet is an infrastructure to give high-speed Internet access to users, but the development in Asia is usually limited within major cities. The characteristics of satellite communications are: (1) wide-area coverage, (2) quick installation, (3) independent from terrestrial infrastructure, and (4) broadcast capability, can be leverage to give broadband access to places where terrestrial infrastructure is still underdeveloped. Therefore, satellite communication is a viable option to build a network in developing regions, such as many parts of Asia.

This paper discusses the architecture of an Asia-wide satellite Internet infrastructure, as an example of how satellite communication can give benefits to the developing Asian regions. Our focus on this research is sharing the technical aspects of networking using satellite link, that we have experienced through design, installation, operation and R&D activities on an on-going satellite Internet in Asia. Hence this paper is expected to give technical suggestions to those who want to join or even launch IP network using satellite communications.

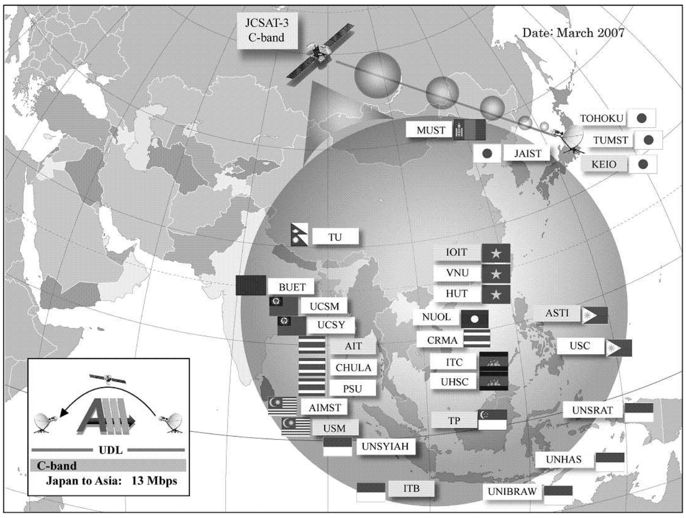

Fig. 1. Satellite UDL in AI^3

1.2 AI^3 Satellite Network

Asian Internet Interconnection Initiatives (AI^3)[6] provides an R&D network in Asia. AI^3 network employs several satellite bi-directional links (BDLs) and one satellite uni-directional link (UDL) to interconnect its participating partners as shown in Fig.1. We have been operating AI^3 since 1996 as a testbed, and the operation of UDL started in 2000.

AI^3 supports School on the Internet Asia (SOI Asia) [11], a project to realize an infrastructure for human resource development by distance education in Asia, where 29 institutes from 13 countries participate as of April 2007. SOI Asia provides its remote lectures over the satellite UDL to share lecture contents, such as video, audio and presentation materials from the lecturer site among the student sites.

AI^3 and SOI Asia have been providing mechanisms to enable an Asia-wide satellite network and digital communications. However, the past achievements of these projects have not satisfied the entire requirement regarding the satellite Internet.

1.3 Paper Organization

Section 2 discusses requirements of satellite Internet. Section 3 presents an architecture of satellite Internet, including current challenges, that is used in AI^3 and SOI Asia. Section 4 qualitatively evaluates the architecture and achievement discussed in this paper. We conclude this paper in Section 5 with raising issues to conduct for future satellite Internet.

2 Design Considerations for IP Networking over Satellite

2.1 Cost Requirement

The cost of hardware equipments is an issue in satellite communications. Not only that the hardware cost discrepancies between receive only stations and transmit capable stations are big, but also transmit capable stations have to be operated by specialists and usually the government requires a certain license for such stations. Transponder costs may also be an issue, as the costs are much higher compared to the costs of terrestrial links, if such links are available. These costs often make it difficult to install satellite communications for IP networking in spite of their characteristics described in Section 1.1. Therefore, the satellite communication technology selection, including hardware and use of transponder, has to be made in such a way to minimize these costs.

2.2 Effective Utilization of Radio Spectrum

The allocation of radio spectrum and its configuration determines the bandwidth for each satellite link. However, radio spectrum is a limited resource, and is shared among transmitting earth stations and their receivers. Therefore, flexibility is required to make effective use of radio spectrum.

Because various traffics flow on the IP network over satellite, it is important to employ suitable networking technologies such as compressing the traffic, prioritizing one type of traffic over the others, and using IP multicast to take advantage of the broadcast nature of satellite links.

2.3 Scalability for Future Deployment

A satellite radio spectrum can be allocated into bi-directional links, but it will severely limit the bandwidth for each link when the number of users is large. The cost implications will also be huge due to the number of installed transmit capable stations. Instead, the radio spectrum can be used as a uni-directional link, taking advantage of the broadcast nature of satellite links. In this case the number of installed receive-only stations can virtually be unlimited, and therefore IPv6 is promising as the network protocol for this link as the address space is large. However, the scalability of the network protocol will be an issue when it is implemented on a large-scale uni-directional link.

2.4 Routing Strategy

Internet access using fiber optic cables has not been widely deployed in Asian regions, and dial-up or DSL connections are the major access. When both satellite path and terrestrial path are available between two communicating nodes, it is often the case that the satellite path has larger capacity but with much larger delay than the terrestrial path. Hence path selection needs to take delay and capacity into consideration. Routing strategy on the end node and operational supports in the upstream network is important to optimize the usage of available paths.

Table 1. Components of Architecture

Index	Component	Target Requirements
S1	One-way shared satellite link	R1, R2
S2	IP Multicast	R2
S3	QoS traffic management	R2
S4	Application gateway for video/audio communication	R2
S5	UDL mesh networking	R1, R2
S6	Transition to IPv6 operation	R3
S7	Scalability of UDL	R1, R4
S8	Sophisticated InterAS Routing using Satellite	R5

2.5 Summary

Based on the discussion above, this research raises 5 requirements for implementation of actual IP network using satellite communications as follows.

R1 Cost reduction on installation and operation of satellite communications
R2 Engineering to maximize utilization of radio spectrum
R3 IPv6 to accommodate a large number of connecting nodes
R4 Scalability of network protocols
R5 Routing strategy in the environment where multiple paths are available including a satellite communication

Following sections discuss how we conduct IP networking with satisfying these requirements.

3 Satellite Internet Architecture

There are several technical components for IP communication over satellite. Fig.2 shows the architecture of satellite Internet used by AI^3. The components of this architecture provide the solutions to meet the requirements set forth in Section2. Table3 summarizes the components and the requirements they will satisfy. Each of these components will be discussed in this paper. S1-S4 have been achieved, and S5-S7 are the current challenges, while S8 is under discussion for the future work.

3.1 One-way Shared Satellite Link

A one-way shared satellite link can be established using satellite receivers, and is effective for (1) an easy solution for broadband Internet connection in the start-up phase of ICT infrastructure, and (2) deployment of large-scale, wide-area Internet services, and (3) an alternative path for the Internet in emergency situations. Using a one-way shared link (uni-directional link) satisfies R1 and R2.

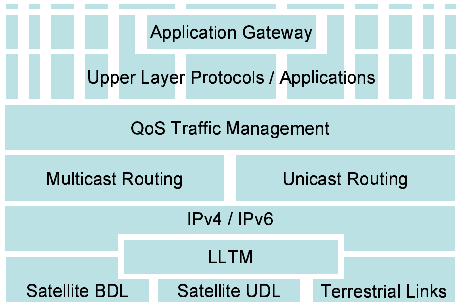

Fig. 2. Technology Architecture

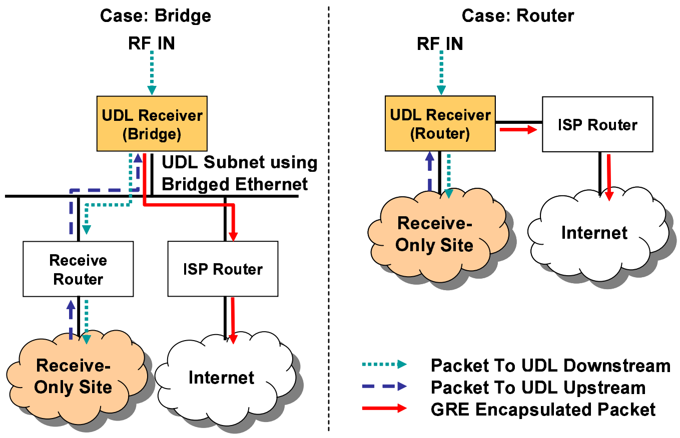

Fig. 3. UDL Receiver Bridge and Router

A receive-only earth station, that does not transmit any carrier to the satellite, is small and inexpensive to install and quick to start operation because it is not necessary to acquire a radio license in many countries.

The current routing protocols on the Internet assume that links have bi-directional communication capability. Therefore, Link Layer Tunneling Mechanism (LLTM) [8] was developed and it provides transparent functionality of routing protocols by emulating a bi-directional, broadcast-capable multiple access link on the UDL.

LLTM specification defines that UDL Fees and Receivers are routers or hosts. However, AI^3 employs an Ethernet bridge implementation for UDL Feed and Receiver. Fig.3 shows the two cases of UDL Receiver, which is implemented as an Ethernet bridge or a router.

In this figure, UDL Receiver Bridge provides Receive Router with a connectivity to the UDL via Ethernet. UDL Receiver Bridge operates LLTM on behalf of Receive Router that only forwards packet from/to the UDL. This implementation allows using an IP router as Receive Router regardless of its vendor and available routing protocols. On the other hand, UDL Receiver Router has to operate not only LLTM but also routing protocols. However, few router vendors support the functionality of, in the case of UDL Receiver, satellite receiver and LLTM in addition to Internet routing protocols. Also, the available routing protocols may be limited or very slow to support new routing protocols. And this is the major reason why AI^3 employed bridge for UDL Feed and Receiver.

3.2 IP Multicast

Broadcast capability is the most important advantage of satellite communication. IP multicast uses that characteristic, and it delivers a single copy of data to multiple destinations at a time. Therefore IP multicast maximizes the utilization of radio spectrum (R2). A satellite link can work as a large-scale IP multicast overlay network for regions where IP multicast is hardly deployed. We have enabled multicast using Protocol Independent Multicast - Sparse Mode (PIM-SM) [9] in AI^3's backbone and the satellite UDL. In order to let multicast traffic flow from its source to the receiver networks via the satellite UDL, the appropriate selection of RP, which is the UDL interface of the upstream router in Feed network, is important in the PIM-SM configuration [12].

3.3 QoS for Classified Traffics

Two limiting factors for satellite bandwidth are satellite bandwidth capacity, including transponder bandwidth, and budget to rent the bandwidth. Therefore, given that the available bandwidth of a link is usually less than the expected amount of the total traffic, we need to prioritize certain types of traffic according to some metrics in order to make effective use of the limited link bandwidth (R2).

AI^3 and SOI Asia have arranged a QoS policy for the UDL usage to support distance education programs. This QoS policy defines the classification of traffic as follows:

1. Control traffic for routing protocols (OSPF, ICMP)
2. Multicast traffic for SOI Asia lectures (Video, Audio, File Transfer)
3. Unicast traffic for terminal access and IRC (SSH, IRC)
4. Transit traffic to the other ASs via receive-only sites
5. Commodity traffic to the satellite UDL prefixes.

To achieve the classification, we have installed the QoS policy using ALTQ[7] HFSC queuing discipline on the upstream network interface of the gateway router to the satellite UDL. Table 3.3 shows the QoS rules for the situations depending whether SOI Asia is having a lecture or not. Each traffic class is guaranteed to a certain rate (denoted as NKbps) and may use a certain percentage of the unused bandwidth. The total bandwidth of the AI^3 uni-directional link is 12.6Mbps.

Table 2. QoS Rules of AI^3 Uni-directional Link

Class	Lecture	No Lecture
Control	100Kbps, 1%	250Kbps, 5%
Multicast	4800Kbps, 60%	2000Kbps, 10%
Unicast	—	250Kbps, 5%
Transit	1000Kbps, 25%	3000Kbps, 40%
Commodity	1000Kbps, 5%	1000Kbps, 30%

3.4 Application Gateway for Video/Audio Communication

There are many ways for video/audio applications to be used with the appropriate rate in the satellite Internet with limited bandwidth. For realtime video/audio applications, there are mainly three approaches: (1) transmission of native format without any modification, (2) rate adaptation by an intermediate proxy, and (3) media conversion by an intermediate proxy. Fig.4 shows how the three above mentioned approaches are implemented by the application gateway for SOI Asia remote lectures.

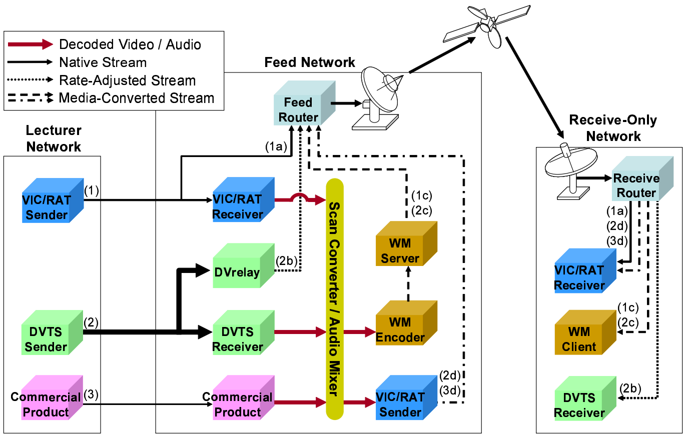

Fig. 4. Application Gateway Overview

Approach (1) uses VIC/RAT to send lecture video/audio, whose transmission rate is already configured to be sent to the UDL without any proxy as (1a) in Fig.4. Approach (2) employs a very high-rate communication such as Digital Vide Transport System (DVTS) [1] whose transmission rate is around 30Mbps. DVrelay[15] reduces the transmission rate to, for example, 6Mbps in realtime before the traffic is forwarded to the satellite UDL as (2b) in Fig.4. Approach (3) uses commercial video conference products such as Polycom or Sony PCS that are available in the lecturer site. Video/audio stream is transferred from the lecturer site to the application gateway, and then the traffic is converted to Windows Media [4] or VIC/RAT multicast stream and transmitted to the satellite UDL as (1c, 2c, 2d, 3d) in Fig.4.

3.5 UDL Mesh Networking

Interconnecting multiple networks using satellite links, there are 3 approaches: (1) Point-to-Point (P2P) mesh, (2) Single Feed (SF) UDL, and (3) UDL mesh[5]. P2P mesh is a topology that uses satellite BDLs to interconnect peer earth stations. SF UDL is a re-definition of the satellite UDL that was discussed in Section 3.1. UDL mesh is a new approach that uses satellite UDLs to interconnect peer earth stations.

In this section, we use ”peer” to denote a network that is connected to the mesh network. We also use ”feed peer” and ”receive peer” to clearly distinguish them in SF UDL.

This paper analyzes these three topologies by the following four aspects; (1) number of required channels, (2) ease of installation, (3) propagation delay, and (4) link bandwidth. UDL mesh requires N channels, where N is the number of peers, to interconnect peers like (c) in Fig.5. And P2P mesh requires $N(N-1)$ channels and SF UDL requires 1 channel like (a) and (b) in Fig.5 respectively.

UDL mesh and P2P mesh require transmission capability to the peering earth station, and in most cases, transmission license, that increases the difficulty to install an earth station. SF UDL requires the earth station with feed peer to have transmission capability and a license. Other peers do not have to acquire any license in most cases, because they only receive a carrier from the satellite.

Propagation delay of UDL mesh and P2P mesh is expected to be one-way delay of a satellite link, which is approximately 250ms. In the case of SF UDL, propagation delay is expected as (1) propagation delay of a satellite UDL from feed peer to receive peers, (2) BDL delay from receive peer to feed peer, and (3) propagation delay of a satellite UDL plus BDL delay from receive peer to another receive peer.

UDL mesh and P2P mesh occupy a dedicated satellite bandwidth, where SF UDL shares a single satellite bandwidth among peers. Therefore, UDL mesh may not satisfy scalability requirement, if a large number of earth station join UDL mesh network to reduce the bandwidth for each link.

The analysis above shows that UDL mesh has advantages and disadvantages compared with the other mesh topology. The biggest benefit is to establish a mesh with direct connections among peers with reduced number of channels and propagation delay. The potential trade-offs are (1) the less scalability of channel allocation, and (2) the less efficiency of link utilization compared with SF UDL, especially when the links of mesh are not fully loaded.

Implementation of the UDL mesh system has been done in the IF environment. Fig.6 shows the system composition of UDL mesh in the peering earth station. UDL mesh bridge is a PC-based system that encodes an Ethernet frame to UDL mesh leaf network into DVB-S format, and reassembles the Ethernet

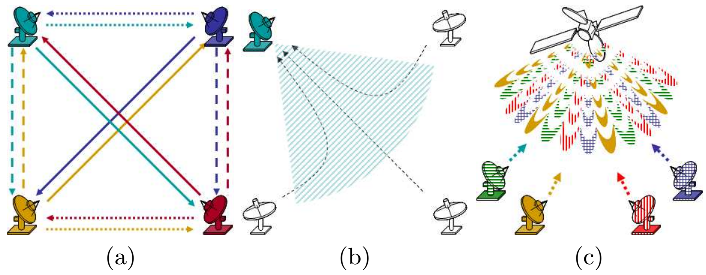

Fig. 5. P2P Mesh, SF UDL, and UDL Mesh

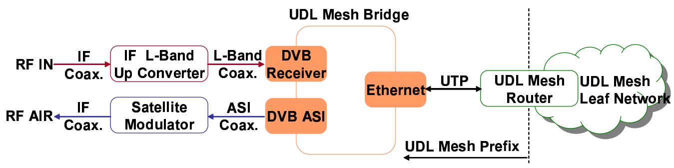

Fig. 6. UDL Mesh System Overview

frame after decoding receiving carrier from the satellite. AI^3 is installing UDL mesh to evaluate its performance and feasibility using satellite spectrum.

3.6 Transition to IPv6 Operation

We started the operation of receive-only sites using IPv4. Then some sites wanted to extend the network to their campus. With the limited IPv4 address in our hand, we see this as a challenge on how to deploy a network using the new Internet protocol, IPv6. Therefore, IPv4 is not feasible to extend global Internet connectivity to developing regions in a scalable manner where a number of potential sites may come up. This is because IPv4 address space is running out and it is difficult to get enough space for emerging regions. Hence, this research is starting the process to migrate applications and routing protocols for the receive-only sites to IPv6 as shown in Fig.7.

IPv6 has a large address space to accommodate many receive-only sites. The problem is that not all applications support IPv6, even though routing protocols already support IPv6. We have proposed an approach that does not generate IPv4 traffic on the satellite UDL subnet even when IPv6 hosts access IPv4 services as shown in Fig.8.

In this figure, one upstream network and two downstream networks are connected through a satellite UDL. Then, our focus is on (1) web traffic, (2) DNS, and (3) protocol translation for other IPv4 services. For a web proxy, we patched Squid[2], that originally supports only IPv4 in order to process requests IPv6 clients. We installed Trick or Treat Daemon (TOTD) [3] to resolve DNS queries,

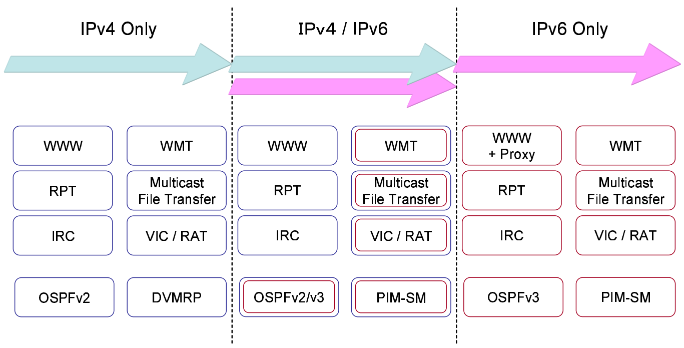

Fig. 7. IPv6 Transition Scheme in SOI Asia

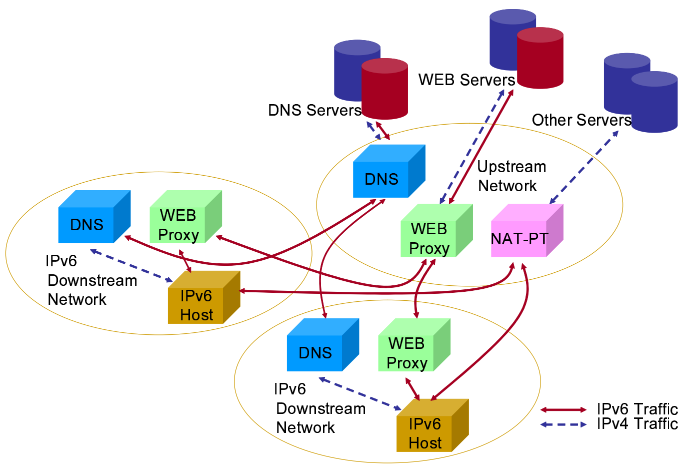

Fig. 8. Host Support in IPv6 Operation

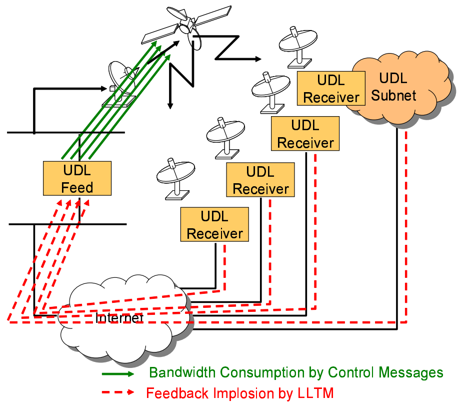

Fig. 9. LLTM Scalability

so hosts without any IPv6 address entries in their DNS records will be given fake IPv6 addresses to be used in conjunction with Network Address Translation - Protocol Translation (NAT-PT)[10].

NAT-PT allows IPv6-only nodes to access other IPv4 services until IPv6 is fully deployed. AI^3 is now testing access to the existing Internet applications from IPv6 receive-only sites. We have held hands-on workshop to distribute know-how of IPv6 operation for SOI Asia partners to AI3 and SOI Asia fully transit to IPv6 operation in the very near future.

3.7 Scalability of UDL

LLTM contributes to deploy receive-only earth stations to join the satellite Internet. However, if the number of receive-only earth stations increases, there is an issue on how to maximize the utilization of UDL bandwidth for service traffics. There are two problems that (1) feedback traffic from UDL receivers implodes at LLTM end point and increase network load, and (2) control traffic caused by network configuration among nodes may consumes UDL bandwidth as shown in Fig.9.

For the solutions, we studied several approaches like (1) to put multiple UDL Feeds with appropriate network distance between them to decentralize LLTM traffic from UDL Receivers, (2) to filter duplicated control messages, such as Multicast Listener Discovery (MLD) Reports, on UDL Feed to prevent forwarding them to the UDL, and (3) optimize the behavior of IP nodes to work in a scalable manner on the UDL.

For the approach (1) and (2), we have been discussing their mechanism to be implemented on a simulator to evaluate their performance. And for the approach (3), we focused on the Prefix Discovery of IPv6 Address Auto-configuration of nodes on the UDL downstream, and have simulated the simple modifications to tune its feedback random back-off timer and the condition that a node may cancel to transmit the feedback message. Also, focusing on scaling multicast sessions, we have been doing efforts to sophisticate such timers and stateful control to suppress the transmission of feedback messages to improve scalability of multicast sessions[14][13].

4 Evaluation

We evaluate our achievement qualitatively by analyzing whether each requirement is satisfied or not and what have been brought through the achievement.

One-way shared satellite link is proved to significantly reduce the cost on installation and operation of satellite link. UDL mesh also exhibited the potential to reduce bandwidth consumption while keeping same information speed as P2P mesh. Therefore, R1 can be said to be met.

The combination of one-way shared satellite link and the deployment of IP multicast on the satellite UDL is the biggest contribution for efficient utilization of radio spectrum. QoS traffic management let prioritized traffic and other traffic coexist by guaranteeing or limiting their bandwidth. The video/audio communication between a very high-speed network and our satellite network can be done by rate adaptation and media conversion using application gateway. Given the situation that SOI Asia lecture can be delivered from the global Internet to Asian regions with as good quality as possible with a very limited bandwidth resource, R2 can be said to be met.

In addition to OSPFv3 and BGP4+ operation in the AI^3's backbone network, transition to IPv6 operation in receive-only network via the satellite UDL will make our entire network ready for IPv6 in both routing and application. Some AI^3 partner sites have already completed the transition to IPv6 operation, and R3 is satisfied adequately and to be met completely in the near future.

For the scalability issues of satellite network, our achievement is still partial and does not completely satisfy R4 at this moment, There can be many network protocols to work on a large-scale satellite UDL, and they may suffer from limited bandwidth and long delay of the satellite. Hence we still need much effort to satisfy R4.

As a result, the evaluation can be concluded that the architecture described in this paper has achieved R1, R2 and R3 adequately. However, this architecture is not completed yet for potential large-scale or advanced usage of this network as set in R4 and R5 requirements.

5 Conclusion

5.1 Summary

This paper has described the benefits and concerns, and current challenges for architecture of a wide-area satellite Internet based on our experiences and implementations in AI^3 network and SOI Asia.

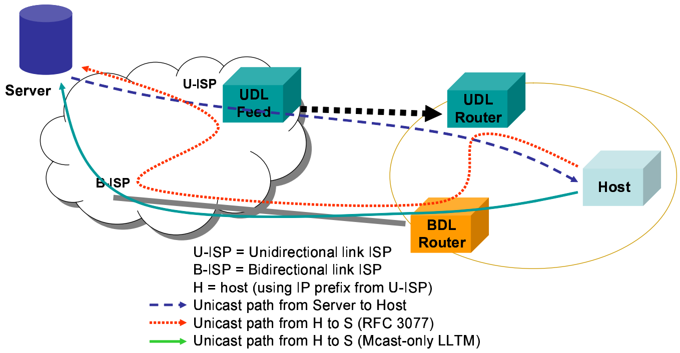

Fig. 10. Unicast on Multicast-Only LLTM

Although our activity is on-going and needs more evaluation for some parts of the architecture, our architecture can be also applied to establish IP networks on other wireless communications because satellite communication is also a part of them. We are going to continue the operation and deployment of satellite Internet in Asia, research and development on the current and potential challenges on technology to establish a better Asia-wide digital communication infrastructure in the global Internet.

5.2 Future Work in Satellite Internet

Multicast-Only LLTM Both multicast and unicast packets from a receive-only site to the rest of the Internet are encapsulated using LLTM based on RFC3077. While this method works well with IP multicast packets, the path for unicast packets is not optimal. A unicast packet has to be sent to the UDL Feed first before being forwarded to its destination, thus creating additional delays. We can alleviate these delays by allowing unicast packets to be forwarded to the destination without undergoing LLTM encapsulation and decapsulation as shown in Fig.10. Multicast packets should be forwarded via RU and encapsulated using LLTM. Thus, this solution preserves the operation of multicast network.

The requirements for this solution are: (1) RO network routes the unicast packets via B-ISP and B-ISP should allow the prefix of the receive-only site, which is assigned from the U-ISP, to pass, (2) LLTM should encapsulate multicast packets and packets for link-local communications to keep the bi-directional emulation of UDL, and (3) multicast routing in the RO network should be separated from unicast routing to allow the normal operation of multicast network.

Satellite Internet for Emergency Situations In the event of emergencies due to natural disasters, etc., we can make use the satellite communication links to provide connectivity to the stricken-areas. The main issue is how to quickly deploy satellite links using this architecture. An approach for this would be to install a receive-only site with a low-bandwidth wireless link as the uplink. This is still an open research issues to be addressed in the future.

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