SATELLITE AND SPACE COMMUNICATIONS

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IEEE COMMUNICATIONS SOCIETY

SSC Newsletter **Vol. 18, No. 2, November 2008**

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The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US -

All conference attendees are welcome to join us in the SSC Committee meeting.

Location: Rosedown 3rd Floor, The Hilton New Orleans Riverside

Date: Monday, 1st Dec. 2008

Time: 10:00 ~ 12:00

Future SSC Meetings

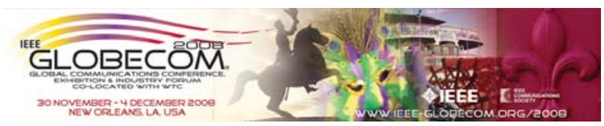
Jun. 2009, Dresden, Germany
Nov.-Dec. 2009, Honolulu, U.S.A
May 2010, Capetown, South Africa

GLOBCOM 2008 SSC Committee Activities

- **GC'08 SAC - Management and Control of Satellite Networks - Satellite and Space Communications Track**
  Tue, Dec 2, 2008 10:00 - 12:00 PM

- **GC'08 SAC - Satellite Systems and Architectures - Satellite and Space Communications**
  Mon, Dec 1, 2008 1:50 PM - 3:30 PM

- **GC'08 SAC - Emerging Access Network Technologies**
  Mon, Dec 1, 2008 10:00 - 12:00 PM



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HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
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MESSAGE FROM THE CHAIR

Prof. Takaya Yamazato

Greetings to our members.

Since 1962, the Satellite and Space Communications (SSC) Technical Committee (TC) has been providing a forum for technical advancement of space communications. SSC TC is an international volunteer organization governed by the IEEE Communications Society. The SSC TC meets two times a year during ICC and GLOBECOM conferences, and the meeting is a very good opportunity for all people from industry and academia with any interest in research and development in satellite and space communications. All conference attendees are welcome to attend and those who are attending the SSC TC meeting for the first time will automatically become a member of TC. Please join us to discuss mutual topics of interest in this important field in communications technology. The meeting agenda and other information about SSC TC activities and operation can be found at the TC web page: http://www.comsoc.org/socstr/org/operation/techcom/satellite.html. We also have an e-mail mailing list to inform you various SSC related topics, including information of upcoming conference. Please note that the address has been changed to ssc@scnl.dist.unige.it due to some technical difficulty with the past one, ssc@cassius.ee.usyd.edu.au.

Following our past chairs, Prof. Mario Marchese and Prof. Abbas Jamalipour, I will continue to foster SSC activities, together with our new Vice Chair and Secretary, Dr. Tarik Taleb and Dr. Igor Bisio.

As our past chair, Prof. Mario Marchese, mentioned in the last meeting, the SSC related papers in ICC and Globecom are decreasing. The number of SSC related paper submissions to ICC and Globecom is also decreasing, although the total number of submissions are increasing. The membership development is important issue and we asked Dr. Verma to take a lead on this. In the meantime, I asked IEICE Satellite Communication Technical Committee of Japan for a possible relation with us. They agreed to introduce SSC TC in their web site: http://www.ieice.org/cs/sat/jpn/purpose_e.html. We will also introduce them in our web site. In this way, we can make our web site as a "portal" to SSC related groups. If you are participating in a satellite related committee of the other ComSoc sister society, please let me know.

The field of satellite communications continues to be interesting and exciting. I encourage all who are interested in this field to join our committee.
Visit our website where you can find information on events and upcoming meetings, and interact with committee officers and members.

Prof. Takaya Yamazato, Chair
Satellite and Space Communications Technical Committee

SCANNING THE WORLD

Dr. Giovanni Giambene

Among other events in the field of satellite communications occurred in this year, a special attention is needed for the *International Workshop on Satellite and Space Communications* 2008 (IWSSC 2008), held at ISAE in Toulouse, France, from October 1 to October 3 (www.tesa.prd.fr/iwssc08/). The statistics of IWSSC 2008 submissions are: 83% from Europe, 12% from Asia, and 5% from North and South America. IWSSC 2008 had 15 technical sessions spanning different topics from channel models, to antenna technology, to resource management and transport layer. Three special Sessions were organized with invited speakers dealing with the progress of the ETSI *Broadband Satellite Multimedia* (BSM) standard, the use of satellite for e-health medical services, and IPv6 networking for satellites. All the IWSSC 2008 papers will be soon available through the IEEE *Xplore* Web access. Two IWSSC 2008 papers were awarded and are surveyed below.

The first paper, by Sooyoung Kim (Chonbuk National University, South Korea) *at al.*, entitled "Design of Long Time Interleaver for Future S-DMB Services", proposes an efficient convolutional interleaver for long term fading, designed for future personal mobile satellite services based on *Orthogonal Frequency Division Multiplexing* (OFDM) transmissions (especially mobile WiMAX). The interest is to improve SDMB service considering the impact of the channel for mobile user and interleaving as a countermeasure. The design described in this paper has been adopted as a Korean technical standard of the satellite component of IMT systems.

Moreover, the second paper by Zoltan Katona and Anton Donner (both from the German Aerospace Center, DLR, Germany), entitled "On Mean Visibility Time of Non-repeating Satellite Orbits" investigated the mean visibility time of a non-geostationary satellites with non-repeating ground tracks as seen by a fixed ground station and provided a mathematical analysis for the calculation of visibility time. The proposed approach is in good agreement with simulation results at all latitudes. Hence, the mathematical model is foreseen to be adopted for analyzing and designing complete satellite constellations.

Finally, a special mention is for both the paper by Gabriele Boccolini (University of Pisa, Italy) *et al.*, entitled "Bringing Multimedia Services to Digital-Divide End-users with Smart 2-way Satellite Technologies: the UNIC EC FP6 Project" and the paper by Golam Sarwar (National ICT Australia Ltd, Australia) *et al.*, entitled "Improvements in DCCP Congestion Control for Satellite Links". The first paper proposed a novel two-way broadband satellite architecture that provides TV-Centric triple play services to actual end-users in the home employing DVB-S2 and DVB-RCS together with a newly low-cost defined architecture and ad-hoc interactive Set-Top-Box. While, the second paper proposed modifications to the *TCP-Friendly Rate Control* (TFRC) congestion mechanism from the *Datagram Congestion Control Protocol* (DCCP) to support real-time traffic in satellite links.

Dr. Giovanni Giambene
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FORTHCOMING GLOBECOM AND ICC CONFERENCES

ICC 2009
June 14-18, 2009, Dresden, Germany.
http://www.comsoc.org/confs/icc/2009/index.html
Recent advances in the field of communications will be presented, thereby facilitating scientific idea exchange, the identification of future trends in communications, and the illumination of business opportunities. The conference will be hosted at the International Conference Center, located at the scenic banks of the Elbe river and embedded in the cultural center of Dresden.

GLOBECOM 2009
November 30-December 4, 2009, Honolulu, Hawaii, USA
http://www.ieee-globecom.org/2009
The theme of the IEEE GLOBECOM 2009 conference is “Riding the Wave to Global Connectivity,” the conference covers the entire range of communications technologies, offering in-depth information on the latest developments in voice, data, image, and multimedia.

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

MILCOM 2009
October 16- 21, 2009, Boston, MA, USA
http://www.milcom.org/
MILCOM 2009 is soliciting both unclassified and classified papers (up to DoD Secret) relevant to communications and information processing system technologies and capabilities that address the 21st century challenges of National Defense, Homeland Security, Disaster Response and Interoperability as summarized above. Industry, academic and government organizations from both the US and countries around the globe are invited and encouraged to participate.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
EHF-AEROCOM Exploitation of Higher Frequency Bands in Broadband Aerospace Communications	November 30, 2008 New Orleans, LA, USA	http://wavemission.uniroma2.it/wave/workshop/index.htm
PSATS 2009 International Conference on Personal Satellite Services	March 18-19, 2009 Rome, Italy	http://www.psats.eu/
WCNC 2009 IEEE Wireless Communications & Networking Conference	April 5-8, 2009 Budapest, Hungary	http://www.ieee-wcnc.org/
ICSSC 2009 AIAA International Communications Satellite Systems	June 1-5, 2009 Edinburgh, Scotland, UK	http://conferences.theiet.org/icssc/index.htm
Second Global Satellite Communications Symposium	Nanjing, China, 2009	web site not yet available
SPECTS 2009 International Symposium on Performance Evaluation of Computer and Telecommunication Systems	July 13-16, 2009, Istanbul, Turkey	http://atc.udg.edu/SPECTS2009/
IWSSC 2009 2009 International Workshop on Satellite and Space Communications	10-11 September 2009, Siena-Tuscany, Italy	http://iwssc09.dii.unisi.it/
Ka and Broadband Communications Conference	23-25 September 2009, Sardinia, Italy	http://www.kaconf.org/
TELSIKS 2009 International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Services	October 7-9, 2009 Niš, Serbia	http://www.telsiks.org.yu/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://www.comsoc.org/~ssc/.

Towards Supporting Multicast Multimedia Services over IMS-based Satellite Networks

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Abstract — **Enabling fixed, mobile, and satellite convergence around IP technologies came with the emergence of new classes of value-added services such as multicast multimedia services. IP services promises to open new perspectives for global communication in satellite networks, although it faces many barriers inherent to nature of satellite networks communication. While broadcast push services are naturally supported by satellite networks, the introduction of interactive unicast and native multicast IP services requires different handling and new protocols support for Quality of Service (QoS) provisioning, security and mobility. The efficient support of native multicast requires a rethinking of the underlying transport model that presents much inflexibility in respect to many regards.**

This paper gives a brief presentation of the problem of supporting multicast multimedia services, such as IPTV, over satellite network. The proposed solution is based on the IP Multimedia Subsystem (IMS) concept in which we introduce a new architecture, namely, Satellite IMS (S-IMS). S-IMS defines a control layer on top of IP to enable seamless and efficient provisioning of multicast services over satellite networks. A SIP-based multicast membership management is performed to introduce new functionalities among which group management, authentication, authorization, routing, billing, etc. The objective of this multicast architecture is to favor integration with forthcoming IMS-based NGN and to allow for more efficient spectrum usage.

Index Terms— **Satellite network, converged services, IP multicast, Service delivery platform.**

I. Introduction

In recent years, a growing attention has been given to IP service transmission over satellite networks, especially with the emergence of the new standards such as Digital Video Broadcast Satellite - Second Generation (DVB-S2) and DVB-Return Channel by Satellite (DVB-RCS). These recent developments turns the satellite network into a viable architecture to support different sort of interactive IP services at global scale and with an affordable cost.

The work of the IETF IPDVB WG in relation to the use of IPv4/IPv6 over the MPEG-2 Transport Stream (TS) and other DVB link technology is a clear indicator of increasing efforts from the IP community to fully integrate satellite communications into NGN as they are being designed.

While the broadcast service is naturally supported by satellite network, unicast and multicast require a special consideration to be deployed in the traditionally asymmetric point-to-multipoint links. IP multicast support over satellite networks has been and continues to be an important component of next-generation interactive and entertainment services. Demands for multicast services are expected to grow and dominate future multimedia services, where group communications starts taking a tremendous dimension fuelled by social networks –based communications and the growing audiences based P2P networks.

All these transformations in communication trends and network convergences ask for more resource-efficient multicast communications. On the other hand, the deployment of multicast service over satellite networks should interact with terrestrial and fixed networking infrastructures to seamlessly bridge multicast services to the satellite audience. However, an effective interaction between satellite networks and fixed networks doesn't go without raising some very critical issues such as efficient multicast architecture definition, group management, routing, scalability, and security issues. A main design objective, here, would be to allow for native IP multicast support with IGMP (Internet Group Management Protocol) and multicast routing deployed in order to seamlessly support and deploy legacy IP multicast applications.

Also it is important to consider all possible use cases for multicast communication over a satellite networks and consider both the case a multicast source internal to satellite network, or external to the satellite network.

Multimedia applications requiring one-to-many or many-to-many communications such as IP-based Television (IPTV) applications, digital entertainment video and audio distribution, multisite corporate videoconferencing, broad distribution financial data, stock quotes and news bulletins, database replication, software distribution, and content caching (for example, Web site caching) need an efficient management of networks resources, quality of service, security, scaling factor, etc. As such, multicast routing was introduced in order to reduce transmission costs and to enable group management.

In the rest of this paper, we will first introduce the main issues that face a native support of multicast in satellite networks. Section III describes our multicast architecture that has been designed, developed, deployed in a DVB-S2/RCS system. Finally, we draw some important conclusions in Section IV.

II. Issues of IP Multicast Over Satellite Network

The Internet Group Management Protocol (IGMP) [1] [2] in IPv4 is commonly used between hosts and the multicast router to manage multicast groups in the access network. Its operation range is then typically within the local network and serves as an extension/bridge to multicast routing protocols that operate in the core network; it is a common way for end-systems to perform multicast group management in an unified way.

To join a particular multicast group, the host sends out an IGMP Membership Reports (MR). This message is intercepted by the multicast router which should subscribe to indicated multicast address, receive the multicast flow from neighbouring routers, and then forward the flow in the local network. The local multicast router forward the multicast subscription request in the uplink sense through the routing protocol to join the multicast tree distribution of the multicast flow in question. Multicast signaling among routers relies on multicast routing protocols, such as Protocol-Independent Multicast (PIM) family.

The multicast router periodically sends out an IGMP Membership Query (MQ) to verify that an active multicast group in the local network still has members in the access network. If there are no replies to two (or more) consecutive IGMP Membership Queries, a router will timeout the group and stop forwarding its traffic. To enhance the performance, the IGMP protocol exploits the broadcast property in the shared medium such as LAN (Local Area Network) based on Ethernet. In fact, in these LANs, every host can listen to IGMP reports sent by others. Therefore, when a host receives a Query, it randomly sets up a delay timers for each group of which it is a member. After the timer expiration, the host sends out its Report. However, if the host overhears an IGMP reports from other member concerning the same multicast group, it stops its timer and abort the sending of its Report, in order to suppress duplicate Reports in the LAN. By this way, the host suppresses itself from sending the same Report as the router already knows that at least one host on the subnet is interested in the multicast group. This mechanism, known as IGMP report suppression, helps reducing traffic over the local subnet especially in asymmetric networks where the uplink capacity is particularly limited.

Over the satellite link, the Satellite Terminal (ST) uses a Snooping (layer 2) or Proxying (layer 3) techniques to deliver IGMP membership messages to satellite Gateway over the air interface and on behalf of IP end-systems attached to it via a local area network. Both Proxy and Snooper do not alter the IGMP message itself, but they just forward the request further toward the gateway (GW) – see the architecture illustrated in Figure 1.Both Proxy and Snooper reduce the IGMP traffic on the uplink by concentrating and aggregating IGMP replies received from end-systems in a single IGMP message when the received replies concern the same operation on the same multicast group.

A major problem here resides in the fact that the broadcast property exists only on the downlink sense and not on the uplink sense. This essentially means that there will be redundancies introduced by multiple Snooping/Proxying agents operating at different STs using a separate point-to-point channels to the GW.

A. Flooding

In the satellite network, the flooding occurs when many STs (IGMP clients) reply to a broadcast request from the IGMP Query sent out by the router to assess the presence of clients in each multicast group. As highlighted earlier, unlike the LAN, the satellite return link does not provide a broadcast property but only an individual unidirectional connection between each ST and the GW. Typically, STs cannot listen directly to IGMP replies from other hosts. Thus, all the hosts have to respond to the IGMP Query sent on the shared downlink, after the expiration of their timer. Satellite multicast groups can be very large and very dynamic as the satellite technology provide large coverage areas with up to few thousands STs in the same satellite spot. This leads to a waste of bandwidth and CPU over the satellite link and the Gateway, respectively. Figure 1 illustrates the problem of IGMP flooding in the satellite context. As depicted in this figure, all the hosts subscribed to a particular multicast group need to respond to the Query messages concerning the multicast group sent by the satellite gateway.

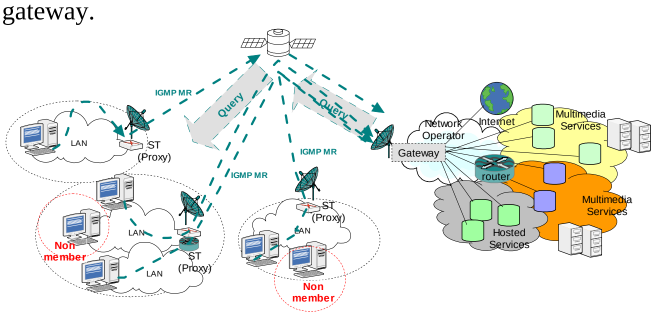

Figure 1: Illustration of the IGMP flooding issue in the satellite context

Some solutions have been envisaged to reduce the flooding problem over satellite network such as the one described in [3]. Also, ESTI, through the specification ETSI TS 102 293 [4], has specified an architecture for reducing the number of report sent out by the IGMP client (hosts) in response to an IGMP Query. The solution described in [4], namely S-IGMP, describes a slightly modified version of IGMP in which some functionalities of the Query (router) have been changed to accommodate satellite communications. Important modifications are related to resending the IGMP Report messages in the forwarding link and fixing the timer value to its maximum to allow for enough time to send again the first received IGMP Reply on the downlink and prevent other STs from sending similar IGMP Replies. The controlled Reports forwarding on the downlink emulates a shared LAN medium where STs hear each other’s traffic, which it is sufficient to ensure report suppression mechanism at the STs.

B. Latency

Another important issue of IP multicast behaviour over satellite network is related to the latency involved by the process of stopping the multicast transmission upon the un-subscription of the last member of the multicast group in question. The latency is the delay needed for the Query to become aware that the multicast group doesn't have any more subscribers in local network, which should prevent the multicast flow forwarding on the local network.

As explained before, if there are no replies to two (or more) consecutive IGMP Membership Queries, the multicast group will be considered as inactive and the router should stop forwarding traffic directed toward that group. Latency is a consequence of the anti-flooding mechanism which increases the timer value to its maximum (the maximum permitted value is 25s instead of the IGMP default value of 10s). The maximum timer value is particularly useful to further space between consecutive IGMP Requests, and thus reduces the traffic volume entailed by IGMP Report responses that could be overwhelmingly high with large multicast groups – this is typically the case of satellite networks where a satellite link covers very large areas. The adaptation S-IGMP tackles this problem by introducing and tuning two IGMP parameters during the leave process. The first parameter is the timer value which is varied by group-specific query messages and it is computed according to the estimated group size. This timer value decreases with the group size in order to increase the responsiveness of the multicast group inactivity detection while controlling the traffic overhead involved by the IGMP Replies.

Instead of having all multicast group members systematically reporting the un-subscription through IGMP, Thus the second parameter used by the S-IGMP is a probability of sending an IGMP Leave to be used by a multicast member to decide whether to send or not an IGMP leave. The probability decreases as the group seize increases. The focus is on keeping the number of IGMP Leave messages as low as possible.

III. IMS-Based IP Multicast over Satellite

IP Multimedia Subsystem (IMS) is emerging as the "*de-facto*" standard technology for next-generation telecom, mobile and broadband networks convergences. It enables service providers to implement all-IP architecture, and moving beyond the limitations of today's network architectures. IMS offers a framework that can be easily leveraged to deliver new revenue-generating services. It defines a number of interfaces and functional blocks to provide: (1) end-to-end multi-vendor interoperability, (2) end-to-end network management, (3) interaction of services layer with control and transport layers for better horizontal engineering and integration of services. This last functionality is exploited in our proposal in the context of IP multicast service delivery over satellite networks, as it will be further detailed in the following.

An IMS-based network defines three planes: data, signalling (control), and application (service) planes. The signalling plane is composed of a set of call session control function nodes (CSCFs) which are, essentially, some sort of advanced signalling proxies. CSCF allows establishing, modifying, and releasing media sessions with guaranteed QoS and AAA support. The service plane is composed of a set of application server aiming to provide a QoS-enabled service to end-users.

IMS architecture provides support for the end-to-end management of media services. We have exploited the strength of this architecture to manage multicast membership over satellite networks. In fact, SIP-based IMS signalling can support a number of functionalities which are not natively supported by IGMP such as QoS, AAA, mobility, etc. An extension of IGMP to support the above functionalities cannot prevent the network from the flooding, latency, and the scalability issues. Furthermore, IGMP cannot be extended easily to carry these advanced functionalities without introducing unnecessary complexity, not to mention the compatibility issues with off-the-shelve IP terminals. Being mainly a layer 3 protocol, it is almost impossible to implement efficient security, billing, and presence management functionalities without interacting with higher-level protocols. It is indeed very important to integrate multicast group management functionalities with higher level service creation, invocation, handling functionalities, etc.

Supporting group management using SIP protocol in the framework of IMS can be used to (1) allow hosts to join and leave multicast group as IGMP does, (2) to verify the authentication and authorisation of users, (3) to signal any cryptographic context (example: using MIKEY), and (4) to support any future extension/augmentation easily. It is important to note that SIP-based multicast membership/group management is used only between the STs and the GW, while IGMP keep being used (in a standard way) between the ST and IP terminals attached to the ST in the local network.

Figure 2 illustrates the functional architecture of the proposed IMS-based IP multicast over satellite that provides a service delivery platform (SDP). As apparent in this figure, on top of the classical IP multicast architecture for satellite network, we integrated a set of IMS elements for advanced multicast management. A SIP client integrated to the Satellite Terminal (ST), namely S-IMS@ST. This allows triggering a more controlled SIP messages for membership management, and acting on behalf of IP terminals attached to the ST. The S-IMS@ST provides proxying, mediation, and aggregation functions of the IGMP group management messages.

A Call Session Control Function (CSCF) element, namely S-IMS@GW, is also implemented to control the satellite gateway (GW) and to manage the service delivery platform. The S-IMS@GW ensures more advanced functionalities that take place at a single multicast group level such as the interaction with multicast routing protocol and multicast flow forwarding functions, multicast group membership management, multimedia stream mixing, security, QoS, etc.

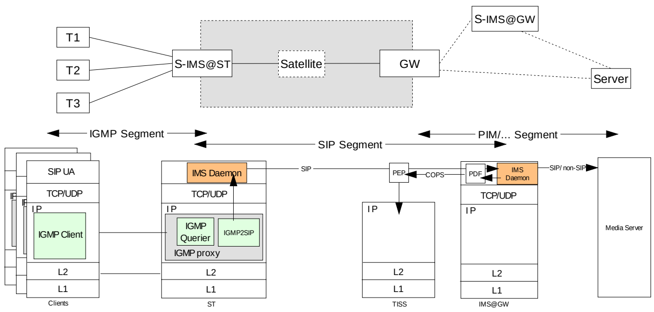

Figure 2: IMS-based IP multicast functional architecture over satellite network

The functionalities provided by S-IMS@ST and S-IMS@GW are essentially related to the management of membership over the air interface with some advanced optional functionalities related to Service Level Specification (SLS) conformance testing, QoS agreement, and other security configuration. Again, the IP terminals connected to the ST continue to subscribe to IP multicast groups by sending IGMP Membership Reports messages as it is done in conventional IP hosts. The IMS-based membership management using SIP is completely transparent to end-users.

The S-IMS@ST intercepts all clients-originating IGMP messages and generates (in a controlled manner) SIP messages towards the GW. It is worth noting that there are no more IGMP messages transmitted in the satellite air interface. The interworking between IGMP and SIP is assured by IGMP2SIP functional block located at the ST. Once a SIP message is received at the S-IMS@GW, a configuration context is created or updated at the satellite gateway (GW). The communication between the S-IMS@GW and the GW itself is ensured by any generic configuration protocol such as COPS protocol as suggested by the IMS standard. To manage the flooding and latency problems we adopted an architecture aiming to manage the message sent over the air interface. The difference of our proposed IMS-based multicast management architecture with the conventional approach based on IGMP resides in the group management logic. Indeed, the Snooping and Proxying mode used to carry IGMP over satellite forwarding link does not introduce major changes in the logic of the multicast membership management. All IGMP messages are transmitted over the air interface leading to a flooding and latency problems. In our architecture, a SIP message is generated only when a specific event occurs such as first subscription or last un-subscription to a given multicast group. This contributes greatly to reduce the volume of multicast membership management traffic transmitted over the satellite air interface. Furthermore, as mentioned earlier, the use of SIP as replacement of IGMP allows the support of new extension such as QoS, AAA, mobility, etc. Both the ST and the GW count continuously the subscription / un-subscription of any member from / to a multicast group. The IGMP-based multicast query procedure is maintained in the LAN part of the ST. This allows keeping track of the number of clients subscribed to a specific multicast group within an ST-controlled subnet. Once the group G becomes inactive, the S-IMS@ST triggers a SIP message to inform the S-IMS@GW to ends packet forwarding for that group. In fact, when all the STs leave the group G, the S-IMS@GW stops effectively the forwarding of the group G's traffic.

IV. Conclusion

Supporting multicast multimedia service over satellite network is a challenging issue due to group management issues and the entailed traffic implosion problem when considering a large multicast group size per link. In this paper, we described the design and implementation of efficient network architecture to support IP multicast over satellite based on IP multimedia subsystem (IMS). This architecture allows managing IP multicast traffic over satellite network with a clear design objective of improving the integration of legacy satellite networks with IMS-based NGN networks.. This architecture performs an interworking between IGMP and SIP for membership management. Various advanced functionalities can be implemented and conveyed via SIP messages such as QoS mechanisms, Authentication, Authorization, and Accounting (AAA), mobility, etc.

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[1] W. Fenner, IETF RFC 2236: "Internet Group Management Protocol version 2" (IGMPv2), nov 1997.

[2] B. Cain and S. Deering and I. Kouvelas and B. Fenner and A. Thyagarajan, IETF RFC 3376: "Internet Group Management Protocol version 3" (IGMPv3), oct 2002.

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[4] TS 102 293: “Multicast group management; IGMP adaptation”, ETSI, Feb 2004.

Investigating operation of the Internet in orbit: Five years of collaboration around CLEO

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Introduction

The Cisco router in Low Earth Orbit (CLEO) was launched into space as an experimental secondary payload onboard the UK Disaster Monitoring Constellation (UK-DMC) satellite in September 2003. The UK-DMC satellite is one of an increasing number of DMC satellites in orbit that rely on the Internet Protocol (IP) for command and control and for delivery of data from payloads. The DMC satellites, built by Surrey Satellite Technology Ltd (SSTL), have imaged the effects of Hurricane Katrina, the Indian Ocean Tsunami, and other events for disaster relief under the International Space and Major Disasters Charter.

It was possible to integrate the Cisco mobile access router into the UK-DMC satellite as a result of the DMC satellites' adoption of existing commercial networking standards, using IP over Frame Relay over standard High-Level Data Link Control, or HDLC (ISO 13239) on standard serial interfaces. This approach came from work onboard SSTL's earlier UoSAT-12 satellite [1].

First tests of CLEO

A large team came together in June 2004 to show that a commercial Internet router could operate in a space vacuum environment. With SSTL and Cisco was NASA Glenn Research Center, who had previously worked with Cisco Systems under a US Space Act Agreement on mobile networking. Also involved for this first demonstration were a number of US military organisations, testing IP-based Virtual Mission Operations Center (VMOC) software from General Dynamics. The VMOC successfully commanded the CLEO router and tasked the UK-DMC satellite from a field tent at Vandenberg Air Force Base, using the Internet to SSTL's ground station [2]. CLEO's use of Mobile IP and mobile networking were also evaluated.

The CLEO ground-based testbed (figure 1), shipped to NASA Glenn, was key to this successful demonstration. That enabled NASA Glenn to become familiar with DMC satellite operation and to provide working router configurations that could be uploaded during very limited operational time with the on-orbit router, when the satellite was not carrying out its primary imaging mission. Direct access to the CLEO router on orbit was later demonstrated at several conferences.

First IPv6 from space

The NASA/SSTL/Cisco team then upgraded SSTL's network infrastructure to support IP version 6, and again used their testbed to become the first to successfully test IPv6 in space with CLEO in March 2007 [3]. CLEO was also configured for IPv4 IPSec use at that time.

First delay-tolerant network bundles in space

Use of the ground-based testbed then shifted away from simply configuring CLEO to programming the SSTL imaging computers that sit alongside CLEO. NASA Glenn is now able to make changes to the RTEMS operating system code on the SSTL computer in its testbed, test those changes, and pass code to SSTL to be uploaded and tested in orbit.

Our team worked to improve *Saratoga*, the fast UDP/IP-based transfer protocol that was developed at SSTL in 2004 to replace an implementation of CCSDS CFDP that was considered slow. *Saratoga* is capable of fully utilizing a link and handles very asymmetric link environments. This has been described to the IETF [4].

In passing periodically over ground stations with limited contact times, the DMC satellites experience link disruption and intermittent connectivity. This is a form of 'Delay-Tolerant Networking' (DTN) [5]. The 'Bundle Protocol' developed by the IRTF DTN research group (DTNRG) is one approach to handling DTN [6].

Our team became the first to successfully demonstrate use of the DTNRG's Bundle Protocol from space, by adopting *Saratoga* as a bundle convergence layer [7] to download an Earth image (figure 2). This 150-megabyte image was downloaded across multiple passes, using proactive bundle fragmentation to avoid the effects of link disruption [8].

Although bundling over the Internet Protocol and *Saratoga* adds no significant benefits to SSTL's existing operational model, the practical experience gained has

a. top view, before adding fans and heatsinks.
b. front view of ports

Figure 1 – CLEO ground-based testbed

helped our team in identifying issues with the Bundle Protocol's design that must be addressed.

The design of the current Bundle Protocol ignores the *end-to-end principle*. The Bundle design does not include error detection or rejection for ensuring reliability in headers or payload data. Adding reliability into the existing Bundle design, by leveraging the not-yet-complete security protocols proposed by the DTN research group, is possible as a workaround, but there are also drawbacks to taking this approach [9].

Summary

The DMC satellites and their use of the Internet Protocol for imaging transfers provide working operational examples of mission-critical use of IP for sensor networks, allowing cost-effective development and easy integration with the terrestrial Internet for data delivery. Use of the efficient *Saratoga* transfer protocol and IP to carry sensor data operates well every day.

The CLEO router in orbit, made possible by the DMC satellites' use of IP, has now been in space for over five years and has been used in orbit over one hundred times.

The team of NASA Glenn Research Center, Cisco Systems and Surrey Satellite Technology Ltd has now gained considerable practical experience and leadership both with taking the Internet into space, and with delay-tolerant networking. The success of these early experiments has made follow-on work possible. That work includes taking Internet routers to geostationary orbit onboard commercial communication satellites.

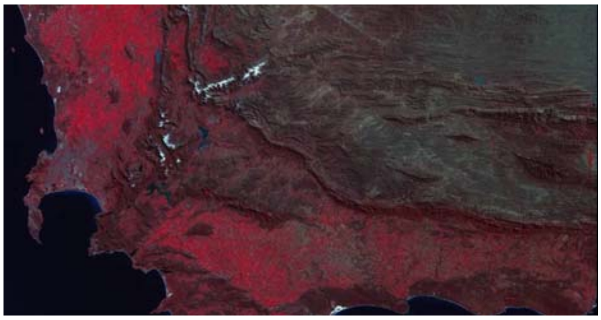

Figure 2 – Image delivered via the Bundle Protocol Cape of Good Hope and Karoo desert

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