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IP Multicast Receiver Mobility Support Using PMIPv6 in a Global Satellite Network

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ABSTRACT

A new generation of satellite systems which support regenerative on-board processor (OBP) and multiple spot beam technology have opened new and efficient possibilities of implementing IP multicast communication over satellites. These new features have widen the scope of satellite-based applications and also enable satellite operators to efficiently utilize their allocated bandwidth resources. This makes it possible for cost effective satellite network services to be provided. IP multicast is a network layer protocol designed for group communication to save the bandwidth resources and reduce processing overhead on the source side. The inherent broadcast nature of satellites, their global coverage (air, land and sea) and direct access to large number of subscribers imply satellites have unrivalled advantage in supporting IP multicast applications. IP mobility support in general and IP mobile multicast support in particular on mobile satellite terminals like the ones mounted on long haul flights, maritime vessels, continental trains, etc., still remain big challenges that have received very little attention from the research community. This paper proposes how Proxy Mobile IPv6 (PMIPv6)-based IP multicast mobility support defined for terrestrial networks, could be adopted and used to support IP mobile multicast in future satellite networks, taking cognizance of the trend in the evolution of satellite communications.

INTRODUCTION

Recently, the role played by satellites in voice and data communication has witnessed a rapid growth. This is due to the advancement in satellite technology like support for regenerative (i.e., demodulation/modulation and decoding/coding of signal) OBP, spot beam technology and the ability to make use of higher frequency bands e.g., the Ka-band. The presence of regenerative OBP in today's satellite systems implies that IP multicast packets can be replicated on-board the satellite, a full-mesh, single-hop communication can be established between two or more satellite terminals/gateways. These features reduce the round trip delay in traditional bent pipe satellite systems by half. Support for multiple spot-beam technology in regenerative satellite systems makes efficient frequency reuse possible within different spot beams. Frequency reuse, efficiently utilizes the allocated frequency spectrum and increases the overall satellite capacity. Also, spot-beams make it possible for the satellite to focus its power over a relatively small area using narrow beams resulting to high power density. High power density supports high data rates, reduces the power requirement and size of satellite terminals and thus reduces the overall cost of satellite communication. Next generation satellite systems like the Inmarsat Global Xpress operate at Ka-band. The advantages of operating at this frequency spectrum are: support for higher data rates, offer more available frequency spectrum compared to the Ku-band (5 times the availability at Ku-band) and less competition for spectrum as there are only very few operational satellites in the Ka-band [1]. These new features have broaden the scope of satellite-based applications and also made satellite communications more competitive in multimedia, integrated voice and data communications against other Internet-based communications technologies.

IP multicast is a network layer protocol which enables a sender to perform a single local transmit operation to deliver the same data simultaneously to a group of interested receivers. This saves processing overhead at the sender associated with sending multiple copies to individual users and bandwidth overhead in the network since only one copy of the data traverse any network link leading to an interested receiver. The large geographical coverage area and broadcast nature of satellite networks are well suited for multicast applications. Unlike in broadcast, where the traffic is flooded in the whole satellite footprint, in IP multicast, traffic is only sent to spot beams that have at least one interested receiver, thus saving bandwidth in those spot beams that have no receivers. IP multicast applications that could be applicable to Mobile Satellite Scenarios (MSS) like in long haul flights, global maritime vessels and continental trains, etc., include: on-demand multimedia content delivery (e.g., IPTV), real-time financial data, software distribution and upgrade, important service information like weather conditions, on-going disaster zones and information, route updates, etc. With all these set of new applications, next generation satellite networks with their support for fast Internet broadband have a unique opportunity to attract new customers and generate new revenues by deploying these new IP-based services. The aeronautical industry which is one of the key customers for mobile satellite services have recently adopted IP as the future network protocol for the Aeronautical Telecommunication Network (ATN) [2]. This opens up new opportunities for satellite-based IP multicast applications on mobile platforms as real-time important service information could be cost-effectively disseminated using IP multicasting, to a group of airlines in mid-air operating in a particular region or route or from an airline to a group of ground offices/emergency services around the world. So, IP multicast support in customers (airliners, trains, ships, etc.) could bring significant financial savings due to the efficient utilization of the allocated bandwidth resources. For satellite operators, the bandwidth resources saved in each satellite footprint could be made available to satisfy the existing customers' demands or sell to new customers.

IP MULTICAST MOBILITY ISSUES IN SATELLITE NETWORKS

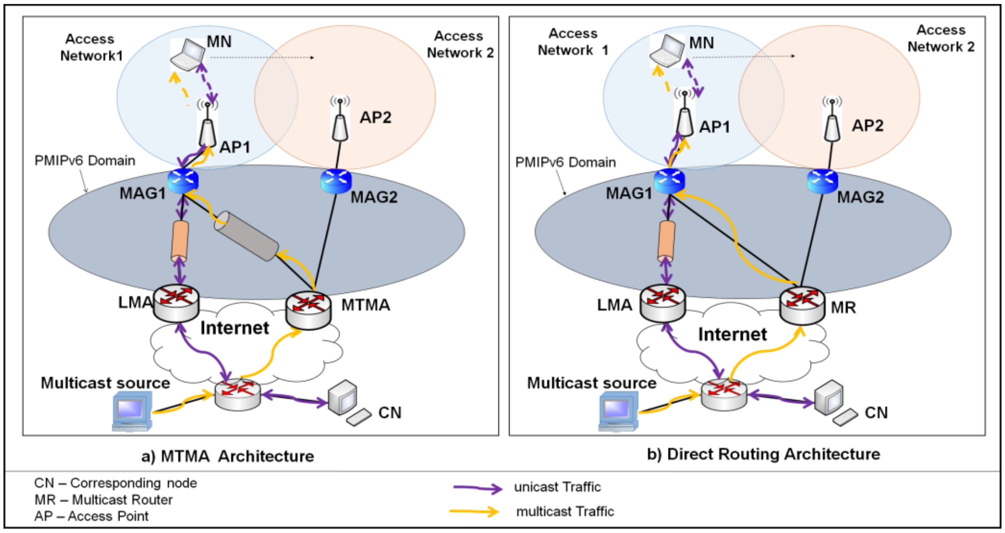
In dynamic multicast group membership, when a receiver joins a multicast group, a multicast delivery tree is established linking the receiver to the multicast source. When the source or receiver moves from one satellite beam to another, the delivery tree is broken because its identity (IP address)/or location have changed, so multicast traffic from source cannot reach the receiver. Assuming that Mobile IP (MIP) is supported within the satellite network, the following two problems arise in such a scenario:

- **Mobile Receiver Problems:** For a mobile receiver to re-establish the delivery tree, it must have to signal its current location to its home agent (HA) or re-subscribe to the multicast group after handover (HO) as a new member using the newly acquired care-of-address (CoA). Considering the long latency in satellite networks, link-switching delay, MIP protocol operations, membership protocol implementation, multicast tree reconstruction, etc., multicast traffic would face a large delay during the HO process, even leading to a break in a real-time multicast application.
- **Mobile Source Problems:** Unlike the HO of a mobile multicast receiver which has just a local and single impact on that particular receiver only, that of a mobile source is a critical issue as it may affect the entire multicast group. During HO procedure, the mobile source cannot send traffic when switching from old set of satellite resources in old beam to the new set in target beam. For an ongoing multicast session, this could results to long multicast latency to the entire multicast group causing serious problems especially to real-time applications. If the HO is between beams belonging to different GWs i.e., gateway handover (GWH), then the IP address of the mobile source will change. This creates a serious problem particularly in source-specific multicast (SSM), where a receiver subscribes to a multicast channel (S, G) i.e., to receive traffic from a specified source identified by its IP address S. When the new IP address (CoA) of the mobile source in the target beam is used as source address to send traffic, the OBP nor designated multicast router in the foreign network cannot forward the multicast packets until the receivers explicitly subscribes to this new multicast channel (CoA, G). This is known as the transparency problem. Also in SSM, a multicast source is always at the root of the source-specific tree. The reverse path forwarding (RPF) check compares the packet's source IP address against the interface upon which the packet is received. The change of the source location and consequently its IP address during GWH, invalidates the existing source-specific tree as any traffic sent by the mobile source from target beam using its home address as source address will result in a failure of the RPF check test and ingress filtering. Hence, the RPF problem point to the fact that the mobile source away from home network cannot use its home address as the source address to send packets.

This paper looks at the multicast receiver problem in detail and presents a PMIPv6-based solution to support mobile receivers using multicast applications in a satellite environment. The solution for mobile sources is out of scope of this paper.

PMIPV6-BASED IP MULTICAST RECEIVER MOBILITY IN TERRESTRIAL NETWORKS

Mobile nodes (MNs) in network-based IP mobility management protocols like PMIPv6 protocol [3] do not participate in network layer HO procedures unlike in host-based mobility protocols (e.g., all variants of MIP, etc.), where the MN is an IP mobility aware node which is fully involved in layer 3 HO signaling. The IETF working group, Multicast Mobility (multimob) charged with the responsibility of providing multicast support in a mobile environment sees PMIPv6 as the way forward for IP multicast mobility support in terrestrial IP networks.



a) MTMA Architecture

b) Direct Routing Architecture

Figure 1 PMIPv6-based architecture for IP Multicast Receiver mobility support

The authors in [4] have proposed an IP multicast receiver mobility support schemes based on PMIPv6 protocol for terrestrial networks. Two operational modes; Multicast Tree Mobility Anchor (MTMA) and Direct Routing (DR) are proposed for IP multicast provision within the PMIPv6 domain with the aim of solving the tunnel convergence problem between the Local Mobility Anchor (LMA) and Mobility Access Gateways (MAGs) that exist in [5]. In this proposal, the IP multicast traffic to or from the domain is separated from the unicast traffic. The unicast traffic passes through the LMA as defined in [3] and multicast traffic through the MTMA in the MTAM mode or the Multicast Router (MR) in the DR mode. The difference between the two operational modes is that in the MTMA, a bi-directional tunnel is established between the MTMA and the MAGs which have MNs with multicast group membership, while in the DR mode, native multicast routing takes place between the MR and MAGs. In both the modes, the MAGs support Multicast Listener Discovery (MLD) proxy function where the MNs are connected to the downstream interface and the upstream interface of the MLD proxy configured to point towards the internal interface of the MTMA or MR. Figure 1 illustrates the two modes in a PMIPv6 domain.

EXISTING SOLUTIONS FOR IP MULTICAST RECEIVER MOBILITY IN SATELLITE NETWORKS

Very little has been written about IP mobile multicast support over satellite networks. The authors in [6] proposed the MIP home subscription (HS)-based and remote subscription (RS)-based approaches to support a mobile Return Channel Satellite Terminal (RCST) whenever it is away from its home network. In the HS-based approach, the CoA acquired by the mobile RCST in a foreign network is registered with its HA through the foreign GW where the mobile RCST is currently located. A bi-directional tunnel is then established between the mobile RCST's HA at home GW and the foreign GW serving the mobile RCST. The HS-based approach, therefore relies on the HA at home GW tunnelling multicast traffic to the mobile RCST in a foreign network. On the other hand, in the RS-based approach, the mobile RCST uses its newly acquired CoA to re-subscribe to the groups that it was a member of before handover. While the HS-based approach suffers from triangular routing problems, high HO latency and signaling overhead, the RS-based approach suffers from multicast delivery tree re-construction, high HO latency and additional signaling overhead.

IP multicast receiver mobility using multi-homing in a multi-beam satellite network is proposed in [7]. It leverages on the multiple interfaces for seamless HO provision whenever a mobile RCST changes its point of attachment from one satellite GW to another. During GWH, it is proposed here that interface 2 should establish connection to the target beam, obtain a CoA and join all the multicast groups that interface 1 is a member of. Once the mobile RCST starts receiving multicast traffic from all the requested groups through interface 2, then interface 1 can de-register from all the multicast groups and shutdown or log off. Despite the advantage of seamless HO, the implementation of this proposed approach requires hardware modification to the standard RCST which usually would have just one satellite interactive interface. This modification could be very expensive. This approach also suffers from high signaling overhead due to the IP address acquisition process for the second interface.

Two common features that all these proposed approaches have are:

- The mobile RCST must be an IP mobility aware node.
- They are all host-based IP mobility management protocols which require additional software and complex security configurations on each mobile RCST for IP mobility support since the mobile RCST must participate in IP mobility signaling during GWH.

These two common features are at the centre of the drawbacks associated with host-based mobility management protocols. The recent trend in IP mobility is shifting from host-based mobility management protocols to more network-based ones.

As seen with the previous sub-section, PMIPv6 provides an elegant solution for supporting receiver mobility in terrestrial networks. However, this has not yet been considered for a satellite network. The following section describes how PMIPv6 can be adopted to support efficient receiver mobility for IP multicast applications with a satellite environment.

SATELLITE PMIPV6 NETWORK ARCHITECTURE FOR IP MULTICAST COMMUNICATION

Proposed Network Architecture

Figure 2 shows the proposed PMIPv6 based network architecture for an IP multicast receiver mobility in a satellite network. The footprint of each satellite here forms a GW_beam (or global beam) representing a separate IP network and has a GW which interconnects the satellite network to terrestrial networks (e.g., Internet). There is usually a Network Control Centre (NCC) associated with each satellite operator. The NCC provides real-time control and monitoring functions e.g., session control, connection control, terminal access control to satellite resources, routing, etc. The Network Management Centre (NMC) is responsible for the management functions of all systems elements in the Interactive Network (IN). In the proposed network architecture shown in Figure 2, it is assumed that:

- Three large GW_beams would be used to provide global coverage in order to constitute one global satellite IN under the administration of one satellite network operator.
- The regenerative OBP on each satellite which decouples the uplink and downlink transponders of each beam has a data link layer capability (layer 2 switch).

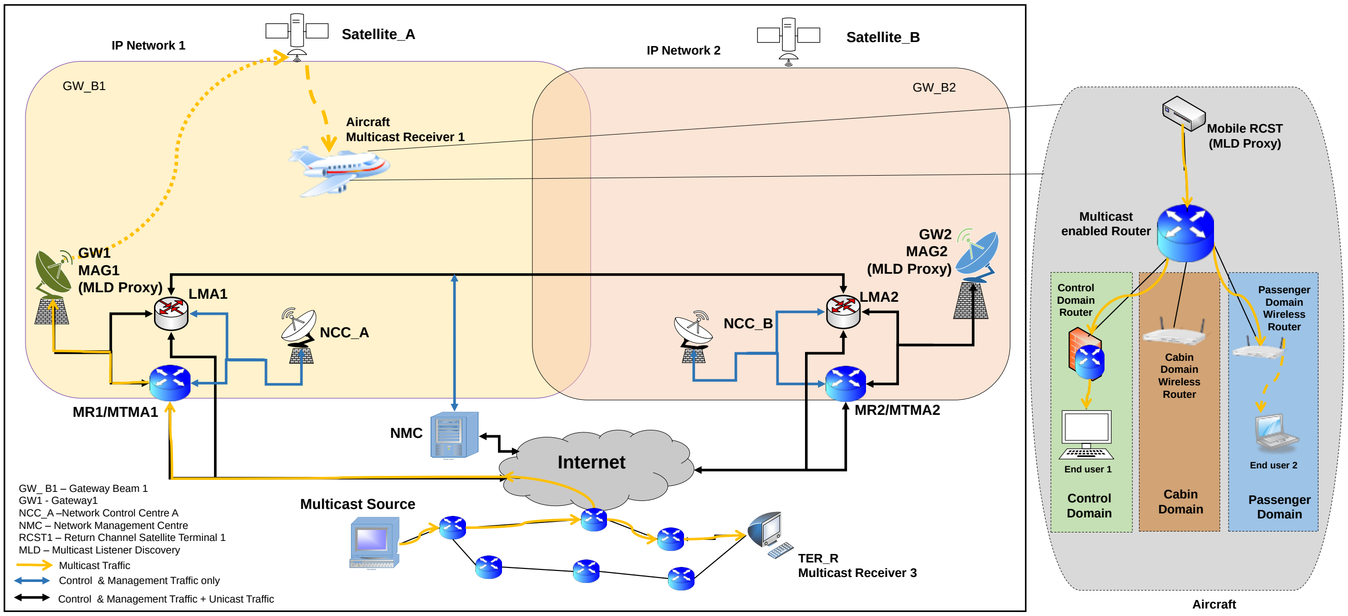


Figure 2. Satellite PMIPv6-based IP multicast communications in mobile scenario

- The regenerative OBP supports on-board replication of multicast packets. Each of the GW_beams is sub-divided into many narrow spot-beams for reasons explained above. The new Inmarsat Global Xpress satellite network has 89 narrow spot beams per satellite.

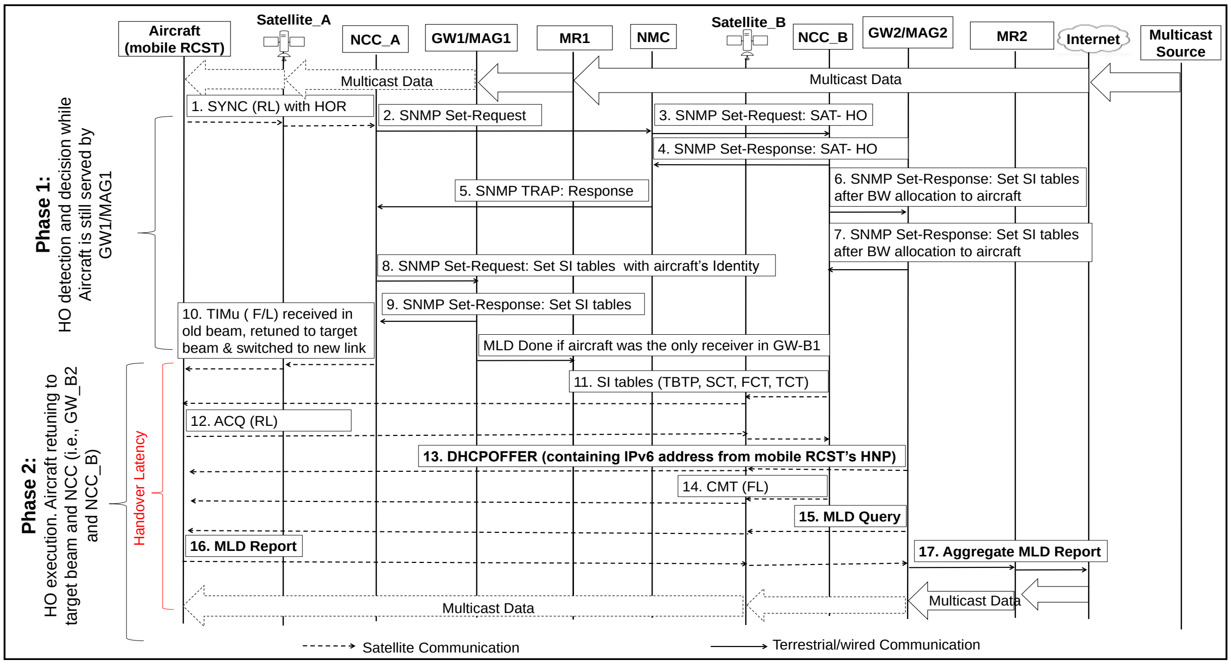
One of the most difficult tasks in deploying PMIPv6-based mobility management in a global multi-beam satellite-terrestrial hybrid network is to select the most suitable location of the LMA, MR/MTMA and MAG taking cognizance of their mobility management functions. Each satellite footprint in Figure 2 is proposed to have one LMA, MR/MTMA and MAG. The LMA is dedicated to unicast traffic, MR/MTMA to multicast traffic and the MAG which is configured at each GW acts as an MLD proxy. The policy profiles of all mobile RCSTs authorized for global network-based IP mobility management are proposed to be stored at all the LMAs and MAGs. Each mobile RCST's policy profile must contain the mobile RCST's identifier (e.g., MAC address), home network prefix (HNP), Link-local address (LLA) and the IPv6 address of its LMA. As shown in Figure 2, the multicast source is assumed to be a fixed node on terrestrial network and while the receivers are located both on the satellite and terrestrial networks and are mobile. The aircraft consists of a mobile RCST and acts as a satellite–based mobile multicast receiver. TER-R is a terrestrial-based multicast receiver. Due to the ability to replicate IP multicast traffic on-board the satellite, only one copy of the multicast traffic is sent up to satellite_A no matter the number of receivers under the satellite's footprint. To efficiently utilize the satellite bandwidth resources, the downlink forwards multicast traffic only to the spot beams that have at least one receiver.

Detailed working of PMIPv6-based IP Multicast receiver Mobility Support in MSS

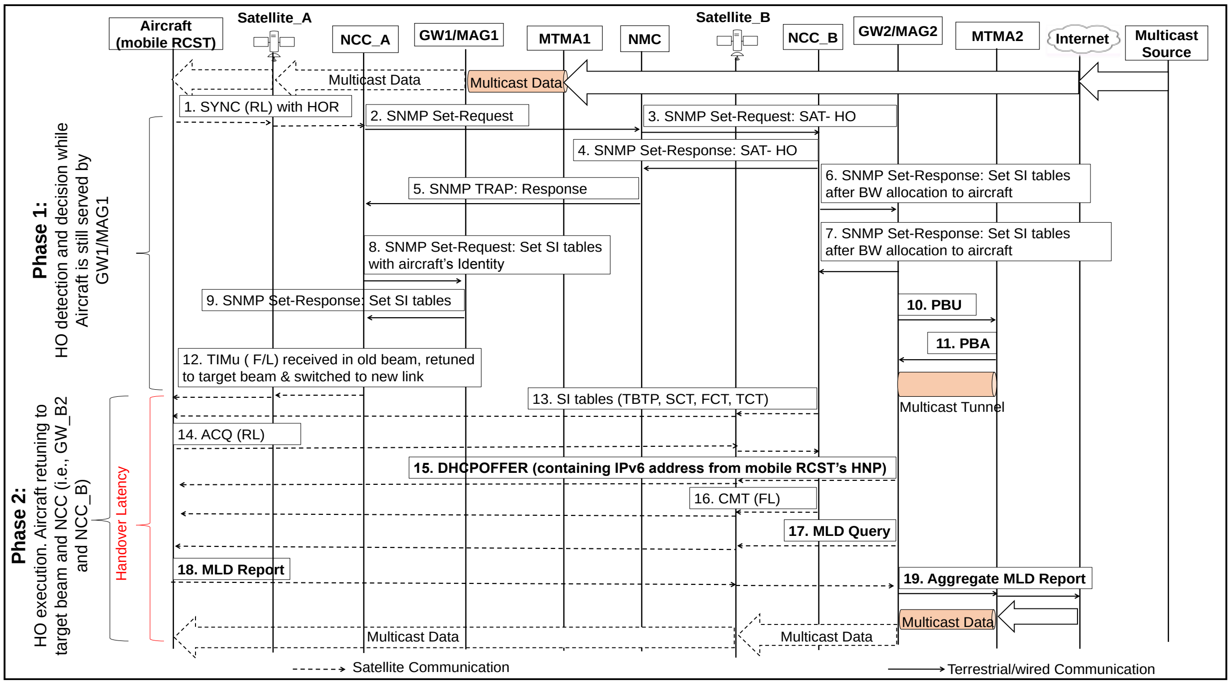
Note should be taken here that the role play by the proposed PMIPv6-based support is mainly at the execution phase of the satellite handover (SH) process. As the aircraft (mobile RCST) enters the overlapping area between GW_B1 and GW_B2, it will undergo a SH. A SH takes place when a mobile RCST moves from one beam into another which belongs to a different satellite. A SH within one IN is coordinated by the NMC. The aircraft is assumed to be equipped with a Global Positioning System (GPS)/Galileo receiver and the global satellite network map. These will enable the aircraft to perform the analysis of its position information and then signal the handover recommendation with a specified target beam to be used in the handover decision process by the NCC. The whole SH process is divided into 2 phases:

Phase 1: HO Detection and Decision: During this phase, the aircraft executes HO detection algorithm as it enters the overlapping area between GW_B1 and GW_B2, and sends a HO recommendation to NCC_A with a specified target beam identity. Upon reception of the HO request, NCC_A using its data base determines that it is a SH. Signaling as shown in Figure 3, between NCC_A, NMC, NCC_B, GW1 and GW2 then follows, resulting in the aircraft acquiring satellite bandwidth resources in GW_B2 (target beam) [8]. When GW2 receives the resource request for the aircraft, MAG2 configured in GW2 gets the aircraft's identity. Now knowing the identity of the mobile RCST, MAG2 can then extract the mobile RCST's HNP, LLA, and the IPv6 address of the LMA serving the aircraft (LMA1) from the MNs' policy profile store contained in all MAGs within the domain as proposed above.

Phase 2: HO Execution: This begins when the aircraft receives the HO command in a Mobility Control Descriptor carried in a Terminal Information Message Unicast (TIMu) [8]. Once the aircraft receives this command, it retunes to the target beam and switches to new link provided by GW2/MAG2. Then MAG2 using the mobile RCST unique LLA extracted from the policy profile, issues the DHCPOFFER message containing an IPv6 address from the mobile RCST's HNP. When the IP mobility unaware aircraft seeing its home network LLA and IPv6 address (from its HNP), it believes that it is in its home network despite the fact that it is now connected to a foreign network.



a. Direct Routing Mode



b. MTMA Mode

Figure 3. SH signaling sequence for PMIPv6-based IP multicast receiver mobility support

The mobile RCST on the aircraft receives its IPv6 address immediately after switching to the target beam, which prevents it from issuing router solicitation message and thus saving satellite bandwidth resources. Following the DHCPOFFER, MAG2 through the mobile RCST's LLA issues the General MLD Query to learn about the multicast group membership status of the newly connected aircraft. In response, the aircraft sends back the MLD Report containing all multicast groups that it is subscribed to. Once MAG2 receives the MLD Report, it checks its multicast membership table to see whether the requested groups already exist. If they are, then MAG2 simply adds the aircraft to the list of downstream receivers and then informs NCC_B to make necessary signaling with the OBP and aircraft to ensure that the aircraft receives the multicast traffic.

In Figure 3, it is assumed that aircraft is the first member of this multicast group in GW_B2. It also shows the difference in signaling for the DR and MTMA mode.

DR mode: The Aircraft being first member of the group in GW_B2 implies that when MAG2 receives the MLD Report from the aircraft, an aggregate MLD Report will be issued to MR2 for all multicast group subscriptions required to serve all its downstream interfaces as illustrated in Figure 3a.

MTMA mode: It is proposed that a MAG should establish only one multicast tunnel to the MTMA located within its satellite footprint for all its multicast needs. This is very important in this satellite scenario to solve the tunnel convergence problem at the MAGs since mobile RCSTs from different GW_beams having different home MTMAs and subscribed to the same multicast group can coincidently find themselves under the service area of one MAG. This tunnel could be pre-configured or established dynamically when the MAG subscribed to its first multicast group. In such a situation, when MAG2 receives the MLD Report from the aircraft, it will issue an aggregate MLD Report to MTMA2 (Figure 3b) for multicast groups which it has not yet subscribed to.

COMPARISON BETWEEN THE PROPOSED PMIPV6 AND OTHER IP MULTICAST RECEIVER MOBILITY SUPPORT SCHEMES IN SATELLITE NETWORKS

Theoretical Comparison

Table 1 summarizes the comparison of some key features of the other existing IP multicast receiver mobility support schemes with respect to the proposed PMIPv6 based approach within a satellite network. From Table 1, it can be seen that in the PMIPv6-based (i.e., network-based) approaches, the mobile subscriber does not require any software/hardware modification in order to join/leave or receive multicast traffic while away from home network, unlike in the other schemes where they are required. This due to the fact that in PMIPv6 protocol, MNs do not participate in IP mobility signaling process. Since in the proposed PMIPv6-based approaches, layer signaling during handover is done by fixed network entities (LMA, MAG, MTMA and MR) and not mobile subscribers, complex security configurations required in MNs during layer 3 handover in host-based IP mobility protocols are completely avoidable in the proposed PMIPv6-based approaches. No software or hardware modification in mobile RCST could lead to a cost reduction in mobile RCST equipment.

	Mobile RCST involved in layer 3 signaling at GWH	**Efficiency of Routing after Handover**	**Layer 3 signaling in satellite network at GWH**	**Mobile RCST hardware change required**	**Mobile RCST software change required**
HS-based	Yes	No	Yes	No	Yes
RS-based	Yes	Yes	Yes	No	Yes
Multi-homed-based	Yes	Yes	Yes	Yes	Yes
PMIPv6-based: DR	No	Yes	No	No	No
PMIPv6-based: MTMA	No	No	No	No	No

Table 1. Comparison of different IP multicast receiver mobility support schemes

Also, owing to the non-participation of the mobile RCST in IP mobility signaling for the PMIPv6-based approaches, no layer 3 signaling takes place over the satellite air interface in a satellite system with a layer 2 OBP capability unlike in the host-based IP multicast receiver mobility support schemes as shown in Table 1. IP mobility signaling in PMIPv6-based approaches is done by fixed satellite earth stations which in most cases are linked by wired terrestrial network. This implies that satellite bandwidth resources that could have used by the remote mobile RCST in signaling each time it changes its IP point of to the network from one satellite GW to another in host-based approaches will be saved.

From Table 1, multicast receiver mobility support schemes in which routing of multicast traffic after GWH must pass through the home GW is considered inefficient (due to triangular routing problems). The proposed PMIPv6-based DR, RS-based and multi-homed-based approaches where traffic can be sent straight to mobile RCST in foreign network after GWH without passing through its home GW is considered to be efficient.

It is clear from Table 1, that the advantages of deploying the proposed PMIPv6-based approaches to support multicast receiver mobility during GWH in a multi-beam satellite network, far out-weigh those of the other existing schemes.

Comparison using Performance Evaluation during SH

Signaling cost and handover latency are the principal factors used in evaluating the performance of any mobility protocol. Signaling cost is defined here as the signaling overhead incurred in supporting a mobile RCST to handover from one GW/satellite to another with minimum disruption of on-going communications [9]. Handover latency on the other hand, is the time period during the handover process when the mobile RCST cannot receive or sent traffic. This handover latency period for the proposed scheme is highlighted in Figure 3.

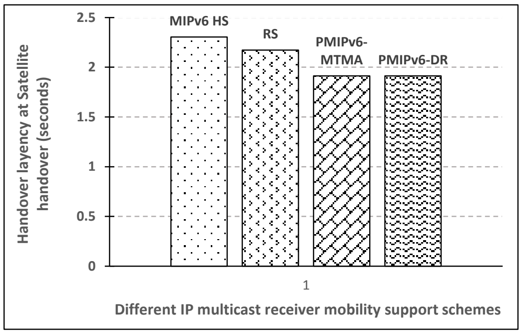
Handover performance analysis of the signaling cost and handover latency using Figure 3 for the proposed PMIPv6-based approaches are performed. Similarly, implementing the MIPv6 HS-based and RS-based approaches on Figure 2, the HO signaling cost and latency for these two schemes are also calculated. The results obtained are presented in Figure 4.

Figure 4a which compares the handover latency of the four schemes, shows that the handover latencies for the PMIPv6-based approaches are generally lower than those for MIPv6 HS-based and RS-based. The lower handover latency in the proposed PMIPv6–based approaches is because the mobile RCST does not participate in IP mobility signaling during HO. Lower handover latency in the proposed PMIPv6-based approaches implies that fewer multicast packets will be lost during HO.

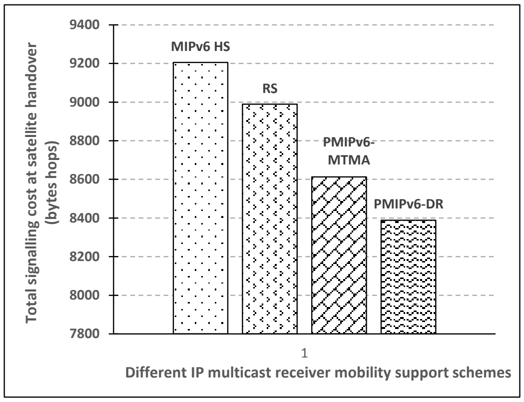
While Figure 4b compares the total signaling cost during SH for all four schemes, Figure 4c compares the signaling cost incurred over the satellite air interface. Figures 4b and 4c show that the PMIPv6-based approaches outperform the MIPv6 HS-based and RS-based approaches in terms of signaling cost. This is due to the efficient and simple HO procedure in PMIPv6 protocol compared to MIPv6. Less signaling cost over the satellite air interface in PMIPv6-based approaches implies that less satellite bandwidth resources are required to support IP multicast receiver mobility. Considering the cost of satellite bandwidth resources, the implementation of PMIPv6-based approaches will save money.

The drawbacks of the proposed MTMA/DR architecture are:

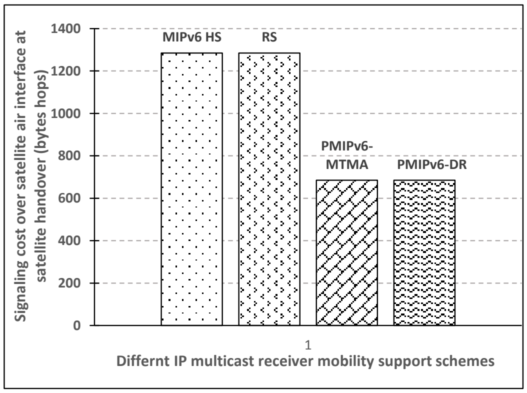
- Cost and effects of multicast tree reconstruction, assuming the MN is the first member of a multicast group under the service of the new MAG.
- Introduction of a new mobility option in the Proxy Binding Acknowledgement (PBA) from LMA to MAG to support dynamic policies on subscription via MTMA/DR [4].



a) Handover latency at SH



b) Total signaling cost at SH



c) Signaling cost over satellite air interface at SH

Figure 4. Handover latency and signaling cost during satellite handover

CONCLUSION

With the increasing support for IP-based applications over satellite networks and increasing demand for ubiquitous communications, support for IP multicast over mobile satellite terminals is gaining importance. Despite the fact that IP multicast saves satellite bandwidth resources and therefore money for satellite operators and customers, support for global mobile IP multicast communications and dynamic group membership over satellite networks still remain a serious problem with no standard solution. This article proposes a PMIPv6-

basedsolution for a global satellite-based IP multicast receiver mobility. The papers details the satellite-terrestrial network architecture for the proposed PMIPv6-based support scheme. The proposed solution leverages on the advantages of the network-based IP mobility management protocol over the host-based ones. It was also seen that the proposed PMIPv6-based support schemes outperform the MIPv6 HS-base and RS-based approaches in terms of signaling cost and handover latency for satellite handovers.

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