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Satellite Mobile Multicast for Aeronautical Communication

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***Abstract*—Satellite communication with its world-wide coverage has now become an indispensable part of the Aeronautical communication. Support for high-speed Internet access by the new generation satellite systems has made the provision of IP-based multimedia applications on-board the aircraft possible at all times. Considering the expensive nature of satellite resources, IP multicast can provide a cost-effective and bandwidth saving means of delivering real-time group communication and streaming media to air passengers and crew during a flight. In IP multicast communication, traffic from the source travels along the established multicast tree to reach all group members. For mobile receivers like the aircraft which may move from one satellite beam to another, then special techniques are required to ensure that a branch of the multicast tree follows the mobile receiver into the target beam. This paper proposes a novel technique based on the Proxy Mobile IPv6 (PMIPv6) protocol to support IP multicast receiver mobility over satellite networks for an aircraft as it moves and changes its point of attachment from one satellite gateway (GW) to another. Performance evaluation shows that the proposed scheme is better than the Mobile IPv6-based approach in terms of GW handover (GWH) latency and number of packets lost during GWH.**

Keywords-Gateway Handover; IP mobile multicast; PMIPv6; Regenerative On-board Processor; Salllite Network.

I. INTRODUCTION

Satellite communication is becoming an integral part of the aeronautical communication system. The support for high-speed broadband Internet access using new generation satellite systems is changing the culture and attitude towards air travel, as air passengers and crew can now experience the same level of Internet-based services as those offered by terrestrial networks. This implies airline operators using satellites, can now offer new IP-based value-added services on board the flight at all times, creating possibilities for an office-like/work environment while flying as well as limitless entertainment that the Internet can offer. The availability of these new services makes air travel more attractive and also can generate new revenues for both the aeronautical industry and satellite network providers.

IP multicast is a technology where a single copy of IP data from a source is delivered simultaneously to a group of interested receivers. This saves bandwidth as only one copy of the data flows along any network link leading to group members. At the source node, processing overhead is significantly reduced as only one copy of data is sent regardless of the number of receivers as compared to sending one copy per receiver. The financial savings that could be made by deploying IP multicast services in aircrafts are huge and therefore, it is imperative for satellite network operators to support IP multicast in mobile satellite platforms like airplanes so as to attract more customers.

A network linking the multicast source and all the multicast group members called a multicast delivery tree is established whenever a multicast receiver joins a multicast group. If a receiver or source moves out of its home network, its location and hence IP address will change. This implies that its attachment to the multicast delivery tree is broken and multicast traffic from the source cannot reach the receiver. Some techniques have been proposed to support mobile multicast receivers/sources in terrestrial networks but due to the long latency and the process of connection is establishment in satellite networks, these techniques are not directly applicable in a satellite environment. Multicast source mobility is out of scope of this paper.

IP multicast receiver mobility support within a Proxy Mobile IPv6 (PMIPv6) domain [1] has been defined in [2] and [3] for terrestrial networks. PMIPv6 protocol is a network based IP mobility management protocol where the mobile node (MN) does not take part in any IP mobility related signalling during handover from one IP network to another within a PMIPv6 domain. This is contrary to host-based IP mobility management protocols like mobile IP, where the MN is at the centre of the network layer handover signalling procedures. In [3], two operational modes are proposed for IP multicast receiver support in PMIPv6 domain: the Multicast Tree Mobility Anchor (MTMA) and Direct Routing (DR). Figure 1 shows the MTMA and DR operational modes in PMIPv6.

The main difference between the two operational modes is that while in MTMA there are bi-directional tunnels between the MTMA and the MAGs which have MNs with multicast group membership, in DR on the other hand, native multicast routing takes place between the MR and MAGs with multicast group membership following multicast tree establishment. Using PMIPv6-based approach instead of any host-based IP mobility management protocol to support

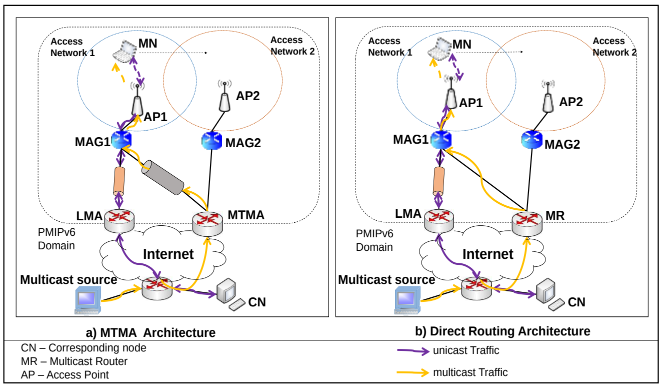

Figure 1. PMIPv6-based architecture for IP Multicast Receiver mobility support.

IP multicast receiver mobility in a satellite environment will have the following advantages:

- Reduced mobile Return Channel Satellite Terminals (RCST) [4] equipment cost and no complex security configuration during handover. Since the mobile RCST does not participate in IP mobility signalling during layer 3 handover, no additional software upgrade to the standard IP software are required in the mobile RCST to support IP mobility. Also, unlike in host-based IP mobility management protocols where complex security configurations are required to prevent identity theft during binding update when the mobile subscriber is away from home network, no such requirements are needed in PMIPv6. This is due to the fact that IP mobility in PMIPv6 is done by network entities rather than the mobile subscriber. All these will culminate in the reduction of the mobile RCST equipment cost.
- Efficient utilization of satellite bandwidth resources. Since the IP mobility unaware mobile RCST does not participate in network layer handover, the satellite resources due to signaling overheads that would have been used in acquiring the care-of-address (CoA) in the foreign network and register this CoA to its Home Agent (HA) or corresponding node are saved in PMIPv6.

Making use of the Digital Video Broadcasting Satellite/Return Channel via Satellite (DVB-S/RCS) [5] network architecture, this paper proposes a novel IP multicast receiver mobility support in a multi-beam satellite network based on PMIPv6 protocol for aeronautical communications. DVB-RCS/RCS2 defines a complete air interface standard for interactive satellite broadband scheme. DVB-RCS/RCS2 which is an open standard, is the only multi-vendor VSAT technology today [6]. Multi-frequency time division multiple-access (MF-TDMA) scheme is used in the return link in DVB-RCS/RCS2 where the RCSTs are allocated time and frequency frames. Thanks to the popularity and vendor independence of the DVB-RCS/RCS2 standard, satellite subscribers with DVB-RCS/RCS2 compliant equipment can now subscribe to most satellite operators and service providers of their choice. These attributes of DVB-RCS/RCS2 standard are beneficial to both the satellite subscriber and satellite operator/service provider as they reduce the satellite equipment and operational costs [7].

II. REALTED WORK

A lot has been written about IP multicast support over satellite networks. This has been mostly in scenarios where the satellite multicast source or receiver is either stationary or moving within the same satellite beam and therefore not undergoing any handover. Support for IP multicast over satellite in mobile scenarios where the satellite multicast source or receiver is moving across different satellite beams is still very rare in open literature today.

The authors in [8] proposed an IP multicast receiver mobility scheme using multi-homing in a multi-beam satellite network. In this proposal, a second satellite interactive interface is proposed for the mobile RCST instead of just one as stated in DVB specification in [5]. Here, it is proposed that when the mobile RCST enters the overlapping area between two beam served by different GWs (i.e., different IP networks), the second interface logs on to the target beam, obtains an IP address and subscribes to all the multicast groups that the first interface is member of. When this second interface starts receiving multicast traffic from the all the requested groups, then the first interface issues an IGMPv3 Leave Report. In this way, a seamless GW handover will take place without any handover latency or multicast packet loss. Despite the advantages of this approach, its implementation requires hardware modification to the mobile RCST equipment, which could be very expensive. Also, being a host-based IP mobility management protocol, the mobile RCST will incur additional signalling cost over the satellite air interface in obtaining the new IP address from the target GW for the second interface while the first interface is still in use.

In the Internet Routing in Space (IRIS) project [9], the authors proposed that a Rendezvous Point (RP) be configured on the space router to support IP multicast on mobile satellite subscribers. Although, the details of how this will actually work is not given, support for dynamic multicast membership where a receiver can join or leave a multicast group at any time could lead to inefficient utilization of the satellite bandwidth resources. The RP on-board the satellite implies that all multicast sources on the ground segment will send their traffic to the RP whether any RCST has subscribed to the group or not. If no one has subscribed to the group, multicast traffic from the ground sources will continue to be sent to the satellite air interface, wasting a lot of expensive satellite bandwidth resources.

III. THE PROPOSED NETWORK ARCHITECTURE

One of the main challenges of employing PMIPv6-based IP mobility management in a multi-beam satellite network is choosing the right location to configure the Local Mobility Anchor (LMA), MAG, MTMA and MR. Figure 2 shows the satellite-terrestrial network architecture used to support IP multicast receiver mobility in a multi-beam geosynchronous (GEO) satellite network. This is part of the satellite network with global coverage. The OBPs in each of the satellites are assumed to have layer 3 routing capability. With the new generation of High-Throughput Satellites (capacity in excess of 100 Gbps per satellite) [10], one GW per satellite footprint may not be able to efficiently handle the high density traffic. So, for maximum spectrum usage and high-throughput in the system, each of the GEO satellites in this network is designed to have three GW_Beams, each representing a separate IP network. A GW_Beam is a wide beam or regional beam which normally has a GW that interconnects the satellite network to terrestrial networks. In each of the GW_Beams, there is a satellite GW that interconnect the satellite network to terrestrial networks. Each GW_Beam in Figure 2 is sub-divided into multiple spot beams in order to increase the overall satellite capacity by making use of the frequency reuse concept in different spot beams and support higher data rates by projecting high power density to each spot beam. Each satellite is controlled by a Network Control Centre (NCC) which provides real-time control and monitoring functions e.g., session control, connection control, terminal access control to satellite resources, routing,

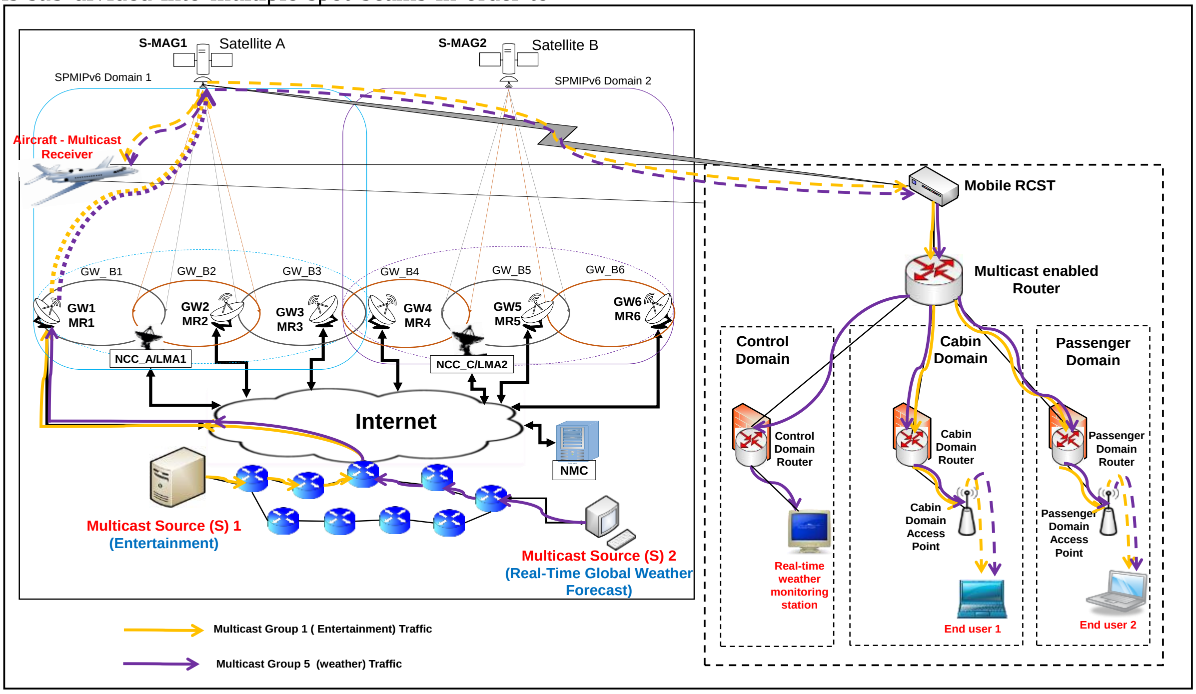

Figure 2. Satellite-based IP multicast receiver support in areonautical communication

etc. It is proposed that the footprint of each GEO satellite which can cover up to one third of the earth surface forms one PMIPv6 domain under the administration of one satellite network operator. One PMIPv6 domain can therefore provide satellite-based services to regional flights. It is proposed that:

- An LMA be configured at each NCC.
- An MAG, hereafter called satellite MAG (s-MAG) be configured on-board each satellite (i.e., on the OBP).
- A multicast enabled router be located at each GW.

The OBP and the s-MAG are controlled by the NCC. The main functions of the LMA are to:

- Keep a binding cache entry (BCE) for each aircraft (mobile RCST) that is away from its home network.
- Track aircraft movements and update the location of aircraft in its database using the BCE and that on the s-MAG after every gateway handover (GWH).
- Issue unique link-local address (LLA) and home network prefix (HNP) [1] to each aircraft from the aircraft's home GW IP address space.

The LMA located at the NCC in a satellite environment is responsible for tracking the aircraft's movement unlike the MAG in [1] because the NCC is the first entity to know about the aircraft's handover request. Since user traffic does not pass through the NCC, the LMA located at the NCC cannot be the topological anchor point for the aircraft's HNPs. So, the LMA here will only perform the mobility management functions. It is proposed that the GW of the beam where the aircraft originates should serve as the topological anchor point for the aircraft's HNP.

The s-MAG on-board the satellite will serve as the Multicast Listener Discovery (MLD) proxy [2, 3] where the upstream interface is connected to the uplink and the downstream interface to the downlink as shown in Figure 3. The advantage of having the s-MAG on-board the satellite is that one s-MAG can now serve the whole PMIPv6 domain (satellite footprint) regardless of the number of IP networks within the PMIPv6 domain. This reduces the number of MAGs per PMIPv6 domain and therefore financial cost. The s-MAG is proposed to have the following functions:

- Keeps a binding cache entry (BCE) for each aircraft that is away from its home network.
- Joins multicast groups on behalf of downstream subscribers i.e., acting as an MLD proxy.
- Provides access links to all downstream subscribers.

Details of the BCE for each aircraft kept by the LMA and s-MAG are shown in Table I. These include the aircraft's current beam and serving GW, identity (MAC address), home IP address (HOA1) from its HNP, unique LLA1 and multicast subscription details.

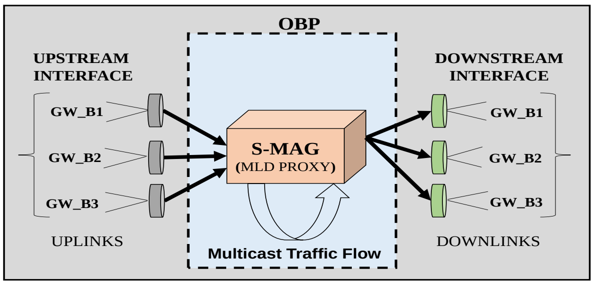

Figure 3. The s-MAG acting as MLD proxy on-board satellite

Table 1. Binding cache entry kept by LMA & s-MAG

Aircrafts (mobile RCSTs)	Beams	GWs	Mac Address	HNP	Link-Local Address	Multicast Subscription
Mobile RCST1	B1	GW1	MAC1	HOA1 (from HNP1)	LLA1	(S1, G1), (S2, G5)

IV. The Proposed PMIPv6 –Based Satellite IP Multicast Receiver Mobility Support for Aeronautical Communication

Figure 2 shows an aircraft connected to the satellite network and subscribed to two multicast groups. It is assumed that Group 1 provides entertainment while group 5 provides real-time global weather forecast to the aircraft. The aircraft is initially at its home GW_Beam i.e., GW_B1. The aircraft is assumed to be equipped with a GPS/Galileo receiver and a detailed satellite network map with beam demarcations which can enable it to determine its position and signal handover with a specified target beam request whenever necessary.

As the aircraft (mobile RCST) enters the overlapping area between GW_B1 and GW_B2, it executes an HO detection algorithm and issues a synchronization (SYNC) burst message to NCC_A, which carries the handover request with the specified target beam. When NCC_A receives the SYNC burst, it retrieves the target beam profile from its database and determines whether the target beam belongs to a different GW. Once this is established, NCC_A updates its service information (SI) tables -Terminal Burst Time Plan (TBTP) Timeslot Composition Table (TCT), Super-frame Composition Table (SCT) and Frame Composition Table (FCT). These SI tables plus the routing update information of the aircraft are then sent by NCC_A to the target GW i.e., GW2 in Figure 2 in an *SNMP-Set Request* message for handover preparation. Upon reception of *SNMP-Set Request* message, GW2 allocates bandwidth resources to the moving-in aircraft according the new TBTP from NCC_A and acknowledged NCC_A with a *SNMP-Set Response* message. Once NCC-A receives the acknowledgement, it issues the *SNMP-Set Request* message to the source GW (GW1) which contains the aircraft's identity and the updated SI tables in preparation to release resources used by aircraft in GW_B1. After receiving the message, GW1 issues an *SNMP-Set Response* message to NCC_A in acknowledgement. When NCC_A receives this acknowledgement, a Gateway Handover (GWH) command present within the Mobility Descriptor carried in a *Terminal Information Message Unicast* (TIMu) message is issued by NCC_A to the aircraft using the old beam GW_B1. At the same time, NCC_A updates the BCEs at LMA1 and s-MAG with a proxy binding update (PBU) to match the aircraft's new location. The issuing of TIMu is quickly followed by that of the updated SI tables from NCC_A to the aircraft. Upon reception of the handover command, the aircraft synchronises with NCC_A and GW2 (target GW) and retunes itself to the target GW. An Update of the s-MAG's BCE for the aircraft triggers the s-MAG to issue *Router Advertisement* (Rtr Adv) message to the aircraft, advertising the aircraft's HNP using its unique link-local address. When s-MAG receives the *Acquisition (ACQ) burst* from the aircraft to NCC_A confirming successful GWH, this triggers the s-MAG now acting as the MLD proxy to issue an MLD Query to the aircraft enquiring its multicast membership status. The aircraft then sends an MLD Report to s-MAG containing all its multicast groups of interest. Upon reception of this MLD Report, s-MAG updates the multicast routing table on its downstream interface and then forwards multicast traffic from all groups of interests to the aircraft. If new multicast groups that the s-MAG is not yet a member of are

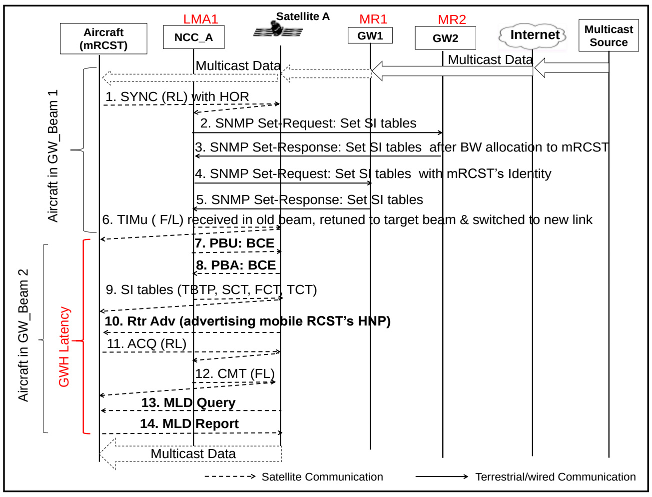

Figure 4. PMIPv6-bnased IP multicast receiver support at GWH in satellite network

contained in the MLD Report, the s-MAG will then issue an aggregate MLD Report through its upstream interface for new multicast subscription to any of the multicast routers (MR1, MR2 or MR3) at the GWs under its footprint. Figure 4 shows the signalling sequence for the proposed PMIPv6-based IP multicast receiver mobility support during GWH in satellite networks. Since the aircraft is still using its home IP address and the same link-local address, it thinks that it is still in its home network despite the fact the aircraft is now in a foreign IP network. This whole process is repeated each time the aircraft moves from one IP network to another within the same PMIPv6 domain i.e., same satellite footprint.

V. Performance Evaluation

Handover latency is one of the most important factors in performance evaluation of mobility protocols. An analytical model for handover latency is developed for the proposed PMIPv6-based and traditional MIPv6-based approaches. The MIPv6-based approach comes from the idea of having the RP configured on the space router to support IP multicast on mobile RCSTs [9]. Results obtained from performance evaluation of the two approaches are then compared.

Table 2. Parameter values for handover analysis

Notation	Description	Value
M_{SYNC}	SYNC message size	12 bytes
M_{SNMP}	SNMP Request/Response + SI tables message sizes + RUI + allocated BW and IP address	636 bytes
M_{TIM}	Terminal Information Message size	35 bytes
M_{SI_t}	SI tables (TBTP, SCT, FCT, TCT, MMT) message size	152 bytes
M_{ACQ}	Acquisition Burst message size	12 bytes
M_{CMT}	Correction Message Table size	30 bytes
M_{Rtr}	Router Advertisement message	80 bytes
$M_{PBU/PBA}$	Proxy BU & BA (PBU & PBA) message	76 bytes
$M_{BU/BA}$	BU/BA message size	72 bytes
M_{DHCP}	DHCPDISCOVERY/DHCPOFFER/ DHCPRQUEST/DHCPACK message size	300 bytes
M_{MLD}	MLD Join message size	72 bytes
h_{2ST}	Number of hops between any 2 satellite terminals	2
L_{Sat}	GEO satellite link latency (delay) from RCST to satellite	130 ms

Handover latency is the period of time during handover process where the mobile subscriber cannot receive or send traffic [11]. The parameters contained in Table 2 [11-13] are used in this evaluation. Assuming that signaling traffic during GWH over the satellite and terrestrial links are without errors or retransmission and that queuing and processing delays at each network entity are negligible, then the message transmission delay (D) over satellite link is calculated as [11]:

$$D = \frac{M \times h}{d_r} + L \quad (1)$$

Where M = message size; h = the number of hops between any two satellite terminals, considering the fact that there is a layer 3 routing capability on board the satellite ; L = Satellite link propagation delay; d_r = data rate of satellite link used.

A. The proposed PMIPv6-based approach

The GWH latency for the proposed PMIPv6-based approach using Figure 4 is given by:

$$L_{HO}^{PMIPv6} = T_{Tx/RX} + 2D_{PBU/PBA}^{Sat} + D_{SI\_t}^{Sat} + D_{Rtr}^{Sat} + D_{ACQ}^{Sat} + D_{CMT}^{Sat} + 2D_{MLD}^{Sat} \quad (2)$$

Where $T_{Tx/Rx}$= Transmitter/Receiver retuning time and the other terms are message transmission delays for the specified messages given by (1) during handover latency period.

Suppose λ_S and E_S are the average multicast session arrival rate at the aircraft and average session length in packets respectively. Assuming that packets transmitted during the handover are not buffered, if Ψ_{lost}^{PMIPv6} is the number of IP multicast packets lost during the handover latency period then according to [14] ,

$$\Psi_{lost}^{PMIPv6} = \lambda_S E_S L_{HO}^{PMIPv6} \quad (3)$$

B. The MIPv6-based approach

With the RP configured on the space router, it can be assumed that MIP bi-directional-tunnelling (home subscription) approach will be used to support IP multicast on mobile RCSTs. This means that the mobile RCST's CoA acquired during GWH, will be registered with its HA on-board the satellite. The HA will then join all the multicast groups of interest to the mobile RCST, receive multicast traffic and tunnel it to the mobile RCST in the foreign network (beam). This implies GWH latency for the MIPv6 approach is given by:

$$L_{HO}^{HS} = T_{Tx/RX} + D_{SI\_t}^{Sat} + D_{Rtr}^{Sat} + D_{ACQ}^{Sat} + D_{CMT}^{Sat} + 3D_{DHCP}^{Sat} + 2D_{Bu/BA}^{Sat} + D_{MLD}^{Wired} \quad (4)$$

Where D_{DHCP} = delay in obtaining CoA, $D_{BU/BA}$ = delay due to binding update, D_{MLD} = delay in HA joining multicast groups.

Similarly to (3) above, number of IP multicast packets lost during the handover latency period is given:

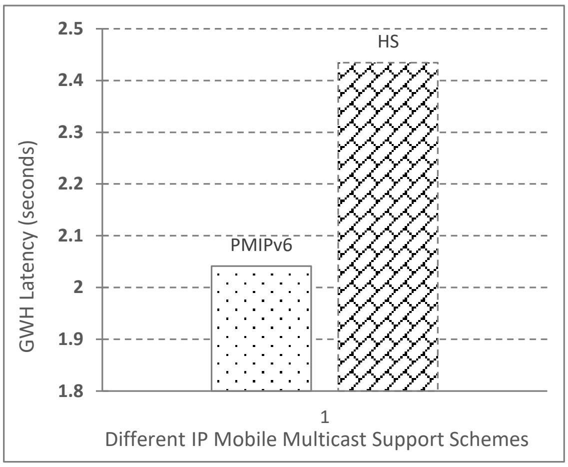

Figure 5. GWH latentcy of different schemes

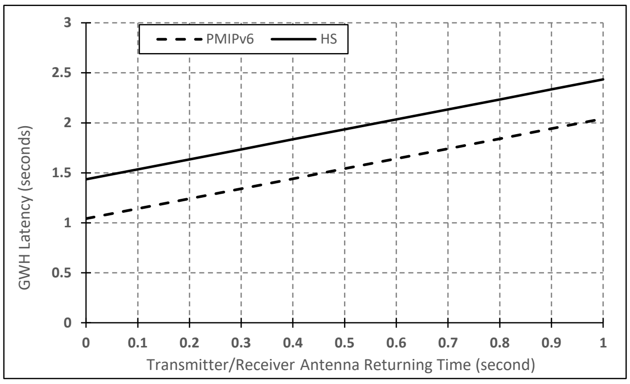

Figure 6. Impact of $T_{Tx/Rx}$ on GWH latentcy

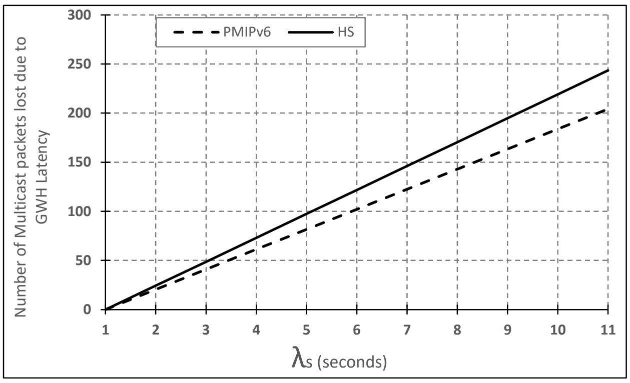

Figure 7. Impact of λ_s on number of multicast packets lost at GWH.

$$\Psi_{lost}^{HS} = \lambda_S E_S L_{HO}^{HS} \quad (5)$$

VI. Numerical Analysis and Results

In addition to the parameters in Table 2, the following are also used: E_s = 10 packets, d_r = 5Mbps, $T_{Tx/RX}$ = 1 second [4, 15].

From Figure 5, it can be seen that the GWH latency for the proposed PMIPv6-based approach is better (about 16.14% less) than that of the MIPv6-based approach (HS). This is mainly due to the fact that the delays incurred in acquiring the CoA in foreign network (different GW_Beam) and binding it to the HA on-board the satellite in the MIPv6-basded approach are saved in the PMIPv6-based approach since the mobile subscriber does not participate in layer 3 handover procedure.

Figure 6 shows how the aircraft's satellite transmitter/receiver antenna retuning time ($T_{Tx/Rx}$) affects the GWH latency in both schemes. For both schemes, the GWH latency increases as $T_{Tx/Rx}$ increases and vice versa. The proposed PMIPv6 still performs better than the HS for every value of $T_{Tx/Rx}$. For example, at $T_{Tx/Rx}$ =0.5 second, the GWH latency for the proposed PMIPv6 is 20.3% less than that for HS. According to (2), (4) and [4], $T_{Tx/Rx}$ is one of the major contributors to higher latencies in beam handovers in DVB-RCS networks. Since GWH latency is directly proportional to $T_{Tx/Rx}$, higher GWH latency in MIPv6 compared to PMIPv6 explains why PMIPv6-based approach is better than the MIPv6-based in Figure 6.

The number of multicast packets lost as a result of GWH latency for MIPv6-based scheme is higher (about 16.14% higher) than that for the proposed PMIPv6-based approach as shown in Figure 7. From (3) and (5) above, the number of packet lost is directly proportional to the GWH latency. Since GWH latency for MIPv6 is higher than for PMIPv6, the number of multicast packets lost is therefore higher in MIPv6 than in PMIPv6.

VII. Conclusion

Satellite communication is the only technology today that can provide communications between an aircraft and the terrestrial networks at all times. IP multicast support in satellite-based aeronautical communications will save a lot of satellite bandwidth resources and could bring significant financial savings to the aeronautical industry. This paper proposes a novel satellite-based IP multicast receiver mobility support for regional airliners using the PMIPv6 protocol. It is shown that the proposed approach is better than the MIPv6-based approach in terms of GWH latency and the number of packets lost during the GWH latency period.

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