# IP Multicast Receiver Mobility Using Multi-homing in a Multi-beam Satellite Network

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***Abstract*—There are several merits of mobile communication devices having multiple network interfaces as compared to traditional devices with just one interface. Smart phones these days are a true example of a mobile multi-homed communication device with heterogeneous network interfaces. Several solutions are available for unicast applications to provide seamless handover using the multiple interfaces of a multi-homed device in terrestrial networks. However, very little has been done on similar support for IP multicast mobility support for mobile satellite terminals in a ubiquitous multi-beam satellite network. Most of the schemes proposed for handovers in multi-homed devices place a lot of emphasis on maintaining the multi-homed device identity especially when the second interface joins the communication session. This increases complexity in the whole system. The issue of maintaining the multi-homed device identity plus the additional signalling messages involve are neither necessary nor desired in an IP multicast communication handover in a multi-beam satellite scenario. This paper seeks to exploit the group communication features of IP multicast (i.e., the fact that anyone can join or leave a multicast group at any time and from any location) and the multiple interfaces of a mobile Return Channel Satellite Terminal (RCST) to support IP multicast communication during handover when a mobile multi-homed RCST changes its point of attachment to the network from one satellite gateway to another.**

***Keywords-Multiple Interfaces; Handover; mobile Return Channel Satellite Terminal (mRCST); Multi-beam Satellite Network.***

## I. INTRODUCTION

Next generation satellite systems, nowadays, are characterised by the support for on-board processing (switching/routing) and multiple spot beams. These new features enable the satellite to make efficient use of its allocated resources and provide cost effective network services. IP multicasting is a technology in which the same data is sent to a group of interested recipients and the network replicating the data as required for delivery until a copy reaches all intended group members. In a multiple spot beam satellite network scenario, IP multicast can be used to communicate important service information like the weather conditions, on-going disaster zones and information, route updates, etc. in long haul flights, global maritime vessels and continental trains. Multicasting this information to all the interested parties rather than individually informing them (i.e., unicast) would save a lot of satellite bandwidth resources.

With an increasing mobile society like ours today, the need for mobility support for IP multicast especially in satellite networks with the potential to provide ubiquitous communications cannot be overemphasised.

Digital Video Broadcasting (DVB) [1] is an open standard published by European Telecommunication Standards Institute (ETSI) describing digital broadcasting using existing satellite (DVB-S), cable (DVB-C), and terrestrial (DVB-T) infrastructures. While originally DVB was designed primarily for audio and video broadcasting, the growth of the Internet and broadband data services has led to the development of the DVB networks to support the transport and delivery of IP based traffic. The Digital Video Broadcasting Return Channel Satellite (DVB-RCS) provides the mechanism to use a satellite as a send data on the return path via the satellite. The large geographic coverage and broadcast capabilities of the DVB-S/RCS network has the advantage of providing IP based services to areas where the deployment of terrestrial infrastructure is uneconomical or impossible.

Based on the possible network topologies, a DVB-S/RCS network support two types of IP multicast services, i.e., star and mesh IP multicast [2]. In star IP multicast, the multicast sources is assumed to be located on terrestrial network which sends the multicast data to the Regenerative Satellite Gateway (RSGW) which in turn forwards the multicast traffic to several RCSTs [3] in the satellite network. On the other hand, in Mesh IP multicast, the source and receivers are all RCSTs of the same interactive satellite network. Each RCST here may have one or more user terminals behind it.

This paper focuses on IP multicast receiver mobility which is the ability of a moving satellite terminal to continue receiver multicast traffic as it moves and changes it point of attachment within the satellite network from one satellite gateway (GW) to another. This is known as gateway handovers. This paper shall focus on the star IP multicast service in which a mobile receiver (i.e., an aircraft) with an on-going multicast session connected to a geosynchronous (GEO) satellite has to undergo a GW handover.

Due to the large round trip delay in GEO satellite networks all handover procedures in multi-beam satellite networks can cause serious link quality degradation or even

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disconnection of an on-going session. During handover, there is a time period when the mobile node cannot receive or send traffic because of the link switching delay. This period of time known as the handover latency constitutes the primary cause of packet loss during handovers. Longer round trip delays in DVB-S/RCS satellite networks imply longer handover latency meaning more packets loss.

Recently, mobile communication devices with multiple network interfaces (e.g., smart phones) are becoming more and more common. Currently, multi-homed mobile devices are mainly used for maintaining connectivity and achieving desired application quality of service. For example, when link quality on a given network interface drops below a certain threshold value, the multi-homed mobile device will initiate a handover to another network interface with better link quality. A common example of this is the handovers between 3G, HSPA and HSPA+ networks in new smartphones when travelling in a car from one city to another. This paper proposes a novel multi-homing based solution for achieving seamless mobility for IP multicast application in multi-beam satellite networks.

The rest of the paper is organized as follows. Section II presents the general gateway handover signalling sequence and some existing IP multicast receiver mobility solutions that may be adopted for satellite networks. In Section III, the proposed multi-homing based solution for IP multicast receiver mobility is described in detail. The performance evaluation of the proposed system is presented in Section IV. Finally, conclusions are discussed in Section V.

## II. GATEWAY HANDOVER SIGNALLING AND MULTICAST MOBILITY

### A. *Gateway Handovers in a DVB-S/RCS network*

Figure 1 shows the signalling sequence at GW handover [3]. When the Network Control Centre (NCC) receives the synchronization (SYNC) burst from the mobile RCST (mRCST) containing the handover request, it will retrieve the target beam identity from its database and determine whether the beam belongs to a different GW. Once the NCC establishes that the target beam belongs to a different GW, a gateway handover is initiated. The NCC will then update its service information (SI) tables which include Terminal Burst Time Plan (TBTP), Super-frame Composition Table (SCT), Frame Composition Table (FCT) & Time-slot Composition Table (TCT). The NCC will send an SNMP Set-Request message that includes the updated SI tables and the routing update information (RUI) of the mRCST to the target GW to ensure that the target GW gets ready for connection with the mRCST. Upon reception of the SNMP Set-Request message, the target GW will allocate bandwidth resources for the mRCST according to the new burst time plan sent by the NCC. The SNMP Get-Response message is then sent by target GW to the NCC. This is followed by a SNMP Set-Request message from the NCC to the source GW, which includes the mRCST identity and the SI tables. Upon reception of the SNMP Set-Request message, the source GW will start buffering the Forward Link (FL) user traffic to be forwarded to the target GW during handover. The source GW then acknowledges the NCC by sending a SNMP Get-Response message. Once the SNMP Get-Response message is received from source GW, a gateway handover command is issued to the mRCST from NCC in a Mobility Control Descriptor carried in a Terminal Information Message Unicast (TIMu) using the old beam. The source GW now updates its route mapping table and released resources used by the mRCST. Once the mRCST receives the handover command, it synchronizes with the NCC and the target GW, retunes itself to the target beam and receives traffic from the target beam which comes through the target GW.

Hence, it can be seen that for a mRCST with one interface (i.e., one transceiver), there comes a time interval during the GW handover execution phase, when the forward link and/or return link user traffic is discontinued. This time is indicated in Figure 1 and is the time when the mRCST is switching its point of attachment to the network from source GW to target GW. Assuming here that the NCC is located in a different GW from the source and target GWs, handover latency for forward link ($HL_{FL}$) from Figure 1 is given by:

$$HL_{FL} = T_{pd}(FL) + T_{pd}(FL) + T_{D1} + T_{MAX(Tx\_,Rx\_tuning)} + T_{ACQ\_U} + T_{MSL} - T_{pd}(FL) \quad (1)$$

Simplifying gives

$$HL_{FL} = T_{pd}(FL) + T_{D1} + T_{MAX(Tx\_,Rx\_tuning)} + T_{ACQ\_U} + T_{MSL} \quad (2)$$

From [2], $T_{MSL}$ is given by:

$$T_{MSL} = T_{pd(FL)} + T_{pd(RL)} + T_{D2} \quad (3)$$

Combining (2) and (3) and assuming that:

Tpd(FL) = Tpd(RL) = Tpd and TD1 = TD2 = TD3 = TD gives

$$HL_{FL} = 3T_{pd} + 2T_D + T_{MAX(Tx\_,Rx\_tuning)} + T_{ACQ\_U} \quad (4)$$

Similarly, return link handover latency ($HL_{RL}$) is given by:

$$HL_{RL} = 2T_{pd} + 2T_D + T_{MAX(Tx\_,Rx\_tuning)} + T_{ACQ\_U} \quad (5)$$

where,

$T_{pd}$(FL) is the forward link propagation delay
$T_{pd}$*(RL)* is the return link propagation delay
$T_{D1} = T_{D2} = T_{D3} = T_D$ is the processing delay
$T_{Max\ (Tx\_,\ Rx\_tuning)}$ is the Maximum time required for retuning the transmitter (Tx*)* and receiver (Rx) to new frequencies of the target beam;
$T_{ACQu}$ is the acquisition uncertainty. This is the time taken by mRCST to issue the ACQ burst in new beam after complete retuning of Tx and Rx;
$T_{MSL}$ is the minimum time interval from issuing a capacity request in mRCST and the mRCST dispatching traffic in the slots allocated in response to that request.

Based on Figure 1 and the above analysis, the FL handover latency is slightly greater than the RL handover latency.

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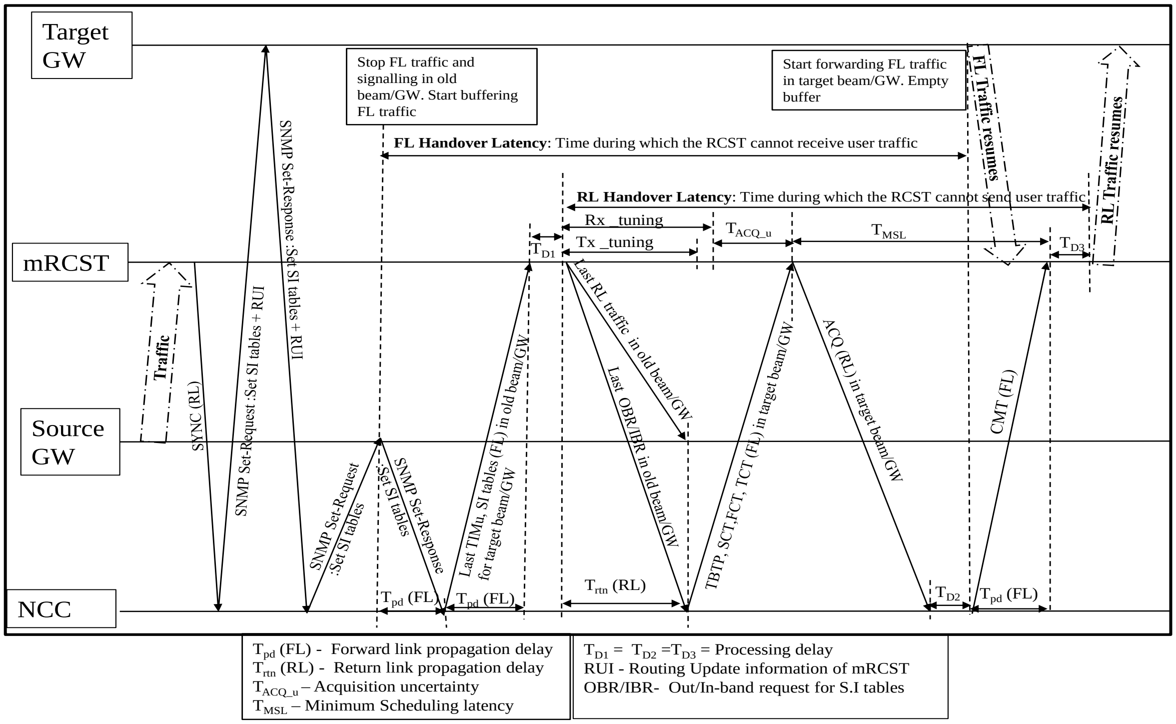


Fig .1. Gateway Handover Signalling Sequence

Since the FL and RL handovers are done in parallel, the handover latency of the one that takes longer to complete then becomes the overall handover latency. So, the FL handover latency here becomes the overall handover latency of the mRSCT.

Due to this link switching handover latency, seamless handover in multi-beam satellite networks cannot be achieved in a mRCST with only one transceiver. This handover latency has a huge impact on real-time applications. Buffering delay/jitter-sensitive application traffic during handover has no benefit since the off-time is rather high and therefore practically impossible to compensate for the delay introduced by buffering.

This handover latency is mainly associated with the link switching procedure in multi-beam DVB satellite networks i.e., the time when the forward link (FL)/return link (RL) user traffic is discontinued as the mRCST is releasing the resources in source beam and acquiring new set of resources in the target beam since the standard mRCST (one transmitter and one receiver) cannot establish connections on both beams simultaneously. This therefore implies that the handover latency is independent of the higher layer mobility management protocols used during GW handover so far as the mobile terminal has just one transceiver.

*B. IP Multicast mobility*

This section presents some existing solution for IP multicast mobility designed for terrestrial networks and the Internet that may be used in the satellite network. In general, Home Subscription (HS) and Remote Subscription (RS) based approaches have been proposed in [4] [5] [6] to support IP multicast receiver mobility in terrestrial networks. In the HS-based approach, the mobile node while away from home network establishes a bidirectional tunnel with its home agent (i.e., a multicast enabled router in the home network of the mobile node). Any multicast traffic received by home network for this mobile node is then tunnelled to the mobile node in the foreign network. HS based approach relies on mobile IP (MIP) [7] for its operation. While such HS based approach could be adapted for use in satellite networks, it inherits the drawbacks of MIP [8] like the triangular routing problem where, any traffic destined for the mobile receiver must pass through its home network. This will further increase the overall handover latency as additional signalling time is required to establish the bidirectional tunnel between home GW and target GW during the GW handover, as this can only be done when the terminal connects to the target GW and receives a new Care-of-Address. Traffic from the multicast source to the mobile receiver will incur additional propagation delay due to triangular routing problem. This triangular routing problem becomes even more acute if the target GW and the multicast source are located in the same terrestrial network as shown in Figure 2. In this case, after GW handover, the multicast traffic will be first sent from the source in target network to the home GW and then tunnelled back to target GW for onward transmission through satellite to the mobile multicast receiver (mRCST).

The RS-based approach, on the other hand, requires the mobile receiver to simply re-subscribe to all the multicast groups it was a member of in the home network after handover to a foreign network. Here, additional time is required for multicast group subscription and tree reconstruction to new location if the mobile receiver is the first member of the group in the new network.

These approaches if adapted for use in satellite networks to support receiver mobility will have no effect on the HL described above. This is because HL is the minimum time required for the mRCST with only one transceiver to release satellite resources in one beam and acquire new set of resources in the next beam and is independent of these mobility support mechanisms. Any such mobility support technique for a mRCST with only one transceiver can only increase the HL given in (2) by adding further signalling delay or multicast tree setup delay.

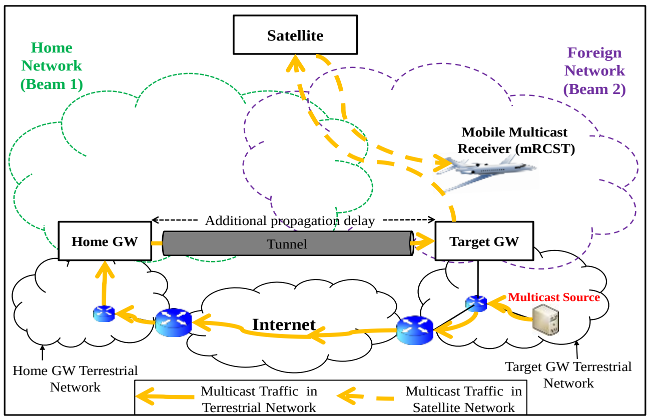


Fig .2. Triangular Routing Problem

A multi-homed LEO satellite connected with two ground stations to support network mobility in space was proposed in [9] and multi-homed end nodes were proposed in [10] to support terminal mobility. The two schemes rely solely on the Stream Control Transmission Protocol (SCTP) [11] to maintain the identity of the multi-homed devices when the second interface joins the communication during handover procedure. Mechanisms to support network and terminal mobility for multi-homed device in IPv6 networks were presented in [12] and [13]. Host Identity Protocol [14] was adopted for providing mobility for multi-homed mobile devices in [15] and [16]. The proposed mechanism in [15] suffers from long handover delay owing to duplicate address detection (DAD), location update, and other signalling overhead. The proposed mechanism in [16] introduces large complexities in access routers like the tracking and updating mobile host location, security signalling, assigning network prefix per host identifier and using the same network prefix within the same network domain to avoid DAD. All these multi-homed based schemes have been designed primarily for unicast communication, where the emphasis is laid on designing protocols/mechanisms to maintain the identity of the multi-homed node when its second network interfaces joins the communication during handover procedure. These system complexities plus additional signalling messages employed to maintain host identity during handover are neither necessary in an IP multicast communication nor desirable in a satellite network with scarce and expensive satellite resources.

## III. PROPOSED MULTI-HOMING BASED IP MULTICAST RECEIVER MOBILITY

In order to reduce the link handover delay described in the previous section, the proposed method leverages on the group communications features of IP multicast and the fact that anyone can join or leave a multicast group at any time. Figure 3 shows the proposed internal architecture of a multi-homed mRCST for Satellite Interactive System.

Figure 3 contains new features/entities in addition to the standard RCST given in [1]. These include:

- An additional broadcast interface (IF1) (i.e., for receiving data via DVB-S) in the broadcast interface module with its corresponding additional interactive interface (IF1) (i.e., for sending data via DVB-RCS) in the interactive interface module, making the mRCST a multi-homed device.
- A database which holds information about the global map of the interactive satellite network (i.e., information about beams, their locations and frequency, gateways - location and IP addresses) as well as all active connections in the mRCST.
- A message chamber which can issue IGMP join report and leave messages during handover between IF0 and IF1
- The controller which manages the data base, the interfaces and has complete control over which interface the traffic leaves/enters the mRCST especially when the two are active (i.e., during handover)

It is assumed that the mRCST (on aircrafts, ships, trains etc.) knows its complete route map (all beams and GWs along its path) before start of journey. As shown in Figure 3, the multi-homed mRCST contains two pairs of satellite network interfaces, IF0 and IF1 in the broadcast interface module with their corresponding pairs in the interactive interface module. The interfaces in the broadcast interface module are used for receiving FL traffic and signalling while those in the interactive interface module are used to send RL traffic and signalling. If FL traffic is received through IF0 in broadcast interface module, then the reply (RL traffic) will be sent out through IF0 in the interactive interface module. The same holds for traffic received through IF1 in the broadcast interface module.

When the multi-homed mRCST, i.e., the aircraft in Figure 4, with an on-going multicast session through interface IF0 enters an overlapping area of two satellite beams belonging to different GWs, it will detect the presence of the new satellite beam.


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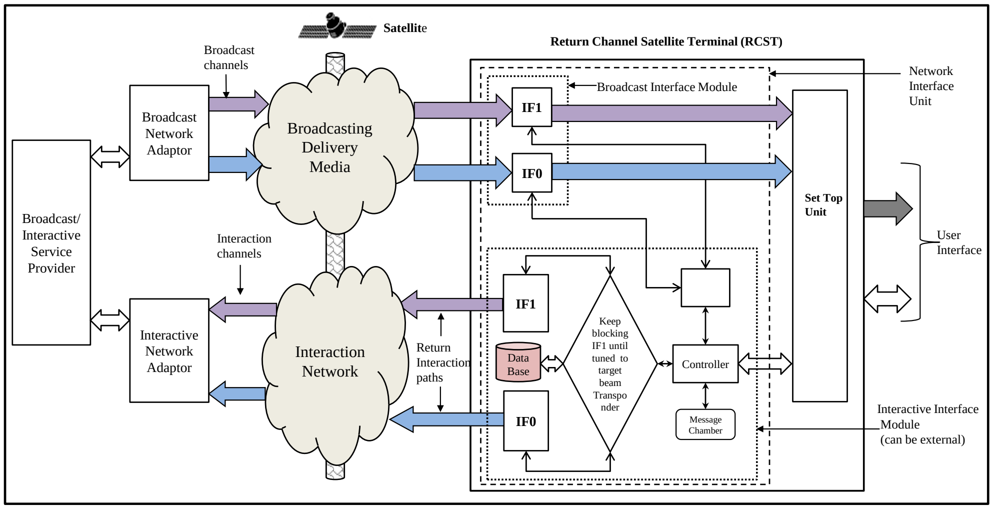


Fig .3. Multi-homed mRCST for Satellite Interactive System

The controller will then consult the database within the mRCST to confirm whether the detected new beam is the target beam. If the detected new beam is the target beam, IF1 through instructions from the controller will then establish a connection with the target beam using normal logon procedure. This is closely followed by the message chamber issuing an IGMP join report through IF1 to the NCC to join all the multicast groups that the mRCST is a member of. Due to the fact that anybody can join or leave a multicast group at any time, the joining of the multicast session by the second interface IF1 does not need to be proven that the two interfaces (IF0 and IF1) belong to the same device. This therefore makes the handover hidden from the satellite network i.e., as far as the satellite network is concerned, the second interface (IF1) may just be another RCST that has logged on to the satellite network and established communication.

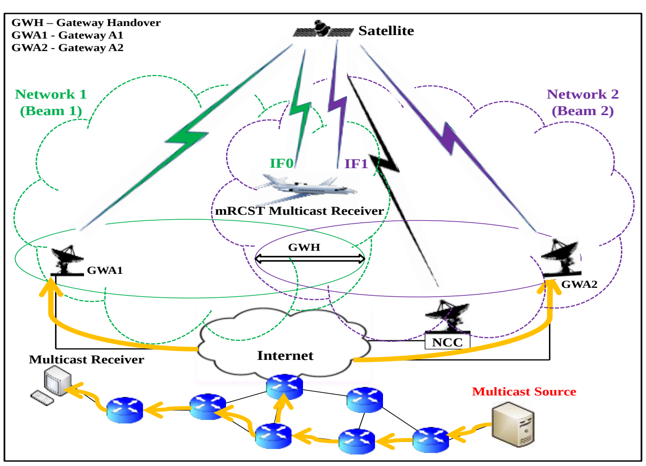


Fig .4. Gateway Handover for a multi-homing enabled mRCST in a Multi-beam Geo Satellite Network.

After this, the controller starts directing all other new communications or connections from the mRCST through IF1. Immediately IF1 starts receiving traffic from the on-going multicast session(s), the message chamber will issue an IGMP leave message through IF0. Eventually, all communications or connections from and to the mRCST are channelled through IF1 and once this happens then IF0 then enters a stand-by/log-off state. Considering the fact that in a GEO satellite network, the area of overlapping beams can stretch for many miles, it is possible to keep the old connection through old point of attachment (GWA1) alive until the new one via GWA2 is set up and all communications transferred to the new link. When the mRCST enters the next area of overlapping gateway beams, the same procedure is followed that will see all communications on mRCST transferred back to IF0 from IF1.

The advantages of this scheme are:

- it is simple to implement
- minimal handover latency – only due to link retuning time
- there are no packet losses at all due to handover as the handover is completely and truly seamless

## IV. Comparison of GW Handover Latency

As stated in Section II, the GW handover latency of a standard mRCST with one interactive interface is given by (4). Assuming that the Super-frame duration is 500ms [17], satellite round trip delay is 250ms and using beam/gateway handover details given in [3], we can establish Table I. According to [3], the $T_D$ in all satellite network devices (NCC, RCST and GW) could take 2 - 3 Super-frames and the $T_{Max\ (Tx\_,\ Rx\_tuning)}$, 1 - 2 seconds. This explains why $T_D$ and $T_{Max\ (Tx\_,\ Rx\_tuning)}$ have two different sets of values in Table I.

**Case 1:** when the $T_D$ and $T_{Max\ (Tx\_,\ Rx\_tuning)}$ take minimum values.

**Case 2:** when the $T_D$ and $T_{Max\ (Tx\_,\ Rx\_tuning)}$ take maximum values.

TABLE I. TIME DELAYS

| | Value | | | |
|---|---|---|---|---|
| | Time in Super frames | | Time in Seconds | |
| | Case 1: Min value | Case 2: Max value | Case 1: Min value | Case 2: Max value |
| $T_D$ | 2 | 3 | 1 | 1.5 |
| $T_{pd}$ | - | - | 0.125 | 0.125 |
| $T_{Max(Tx-, Rx\_tuning)}$ | - | - | 1 | 2 |

Using (4) and the values in Table I, the change in handover latency (HL) with respect to acquisition uncertainty ($T_{ACQ\_u}$) for a mRCST with one interactive interface can be calculated and compare it with our proposed scheme which has two interactive interfaces and a HL of zero.

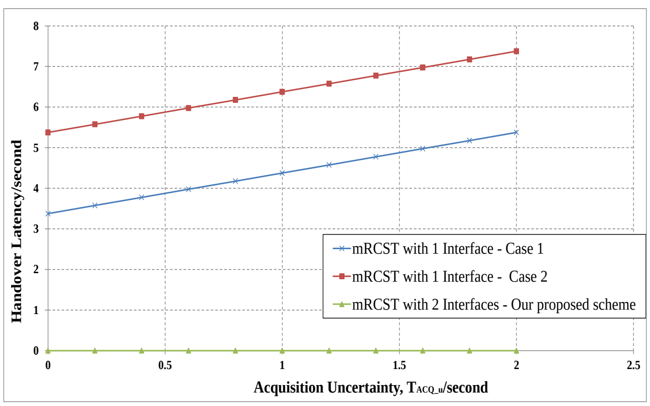


Fig .5. Comparing the Handover latency during GW handover in Geo Satellite Network

Figure 5 shows that the mRCST with two interactive interfaces during GW handover in satellite networks has the best possible handover latency (zero) for IP multicast communication.

## V. CONCLUSION

Based on the DVB specifications, a mobile RCST with a single transceiver will always face a small period of service disruption during the handover phase. Higher layer mobility management protocols cannot remove this intrinsic delay. This paper describes in detail how a multi-homed mRCST can be used to support IP multicast receiver mobility during gateway handover in a global multi-beam satellite network. It proposes the internal architecture of such a multi-homed mRCST. The use of the proposed multi-homed terminal eliminates this handover latency for IP multicast communication over the satellite as it changes its point of attachment to the satellite network from one satellite gateway to another in a global multi-beam satellite network.

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