Source Mobility Support for Source Specific Multicast in Satellite Networks

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***Abstract*—With increasing human mobility and demand for ubiquitous communications, the growth for satellite communications is likely to continue. Recently, IP multicast support over satellites has witness significant increases. Mobility support for multicast receivers as well as sources within a global multi-beam satellite network is very important. Not much research has been done on this area compared to IP multicast mobility support in the Internet. In this paper, we propose a new mechanism to support multicast source mobility for Source-Specific Multicast (SSM) based applications in a multi-beam mesh satellite network with receivers both within the satellite network and in the Internet. In the proposed mechanism, the mobile source remains transparent to the various SSM receivers at all times despite the fact that its IP address keeps on changing as it changes its point of attachment from one satellite gateway (GW) to another. The uniqueness about this proposal is the absence of encapsulation (tunnelling) and triangular routing paths throughout the system and its compliance with DVB-RCS/S2 specifications.**

Keywords-SSM; Mobile Multicast Source; Transparent Satellite; Multi-beam Satellite Interactive Network.

I. INTRODUCTION

IP multicasting is a technology in which a single copy of IP data is sent to a group of interested recipients and the routers (or hosts) in the network replicate the data as required for delivery until a copy reaches all intended downstream group members. In IP multicasting, there may be a many sources sending data to a single multicast group for example: group voice chat. In source-specific multicast (SSM), the group member of such a multicast group, G requests to receive traffic only from one specific source, S. Hence SSM is usually denoted as (S, G) [1].

The handover of a mobile multicast receiver from one point of attachment to another has a local and single impact on that particular receiver only. However, the handover of a mobile source may affect the entire multicast group, thereby making it a critical issue. A mobile multicast source faces two main problems; transparency and reverse path forwarding (RPF).

In SSM, a receiver subscribes to a multicast channel (S, G) [1]. During a handover, as the source moves from one network to another, its IP address will change. When the source uses this new IP address i.e., care-of address (CoA) [2, 3] as source address to send traffic, the multicast router in the foreign network cannot forward the multicast packets until a receiver explicitly subscribes to this new channel (CoA, G). This is known as the transparency problem.

A multicast source-specific tree is associated to source location i.e., the source is always at the root of the source-specific tree. The RPF check compares the packet's source address against the interface upon which the packet is received. During handover, the location of the source will change (and consequently its IP address), thus invalidating the source-specific tree due to the RPF check test. Hence, the RPF problem relates to the fact that the mobile source cannot use its home address in the foreign network as the source address to send packets as this will result in a failure of the RPF mechanism and the ingress filtering [2].

IP multicast over satellites 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.

II. PREVIOUS STUDIES ON SSM

A few mobile source support techniques for SSM have been proposed for terrestrial Internet. These are far from being applicable in a satellite scenario. Due to the problems of transparency and RPF, remote subscription [2, 3, 4] cannot be applied to mobile multicast sources for SSM.

Home subscription [2, 3, 4] in terrestrial Internet on the other hand, can support both mobile receivers and sources (including SSM senders) by use of bi-directional tunnelling through home agent without the problems of transparency and RPF. As shown in Figure 1, once the mobile source leaves its home gateway (GW), it must release the resources in its home GW as it acquires new set of resources in the new GW during the GW handover (GWH) [5]. Following the home subscription mechanism, if bi-directional tunnelling between the home GW and the target GW is used to maintain source identity, the mesh communication concept (i.e., a single hop over the satellite) will be lost and could also results in RPF issues. More so, it is practically impossible for the mobile source to make use of resources under its home GW after handover to a new GW [5]. This implies that bi-directional tunnelling through home agent as mobility support technique for a mobile source in a mesh transparent multi-beam satellite scenario is also not suitable.

In [6] and [7], the authors using the shared tree approach proposed "Mobility-aware Rendezvous Points" (MRPs), which in effect replace the home agents in their role as mobility anchors. There is at least one MRP per domain. The MRPs rely on triangular routing and tunnelling to fulfil their role as mobility anchors during inter-domain tree setup and also re-introduce rendezvous points, which are not native to SSM routing. The introduction of new entities/messages for example, the MRP, new registration message (of mobile sources to MRPs whenever they move into a new domain), MRP Peer-to-peer Source Active (SA) and keep-alive messages (required to track the source's MRP attachment point changes) during inter-domain multicasting, coupled with the modification of the standard Multicast Forwarding Table (referenced by the two addresses home address and CoA instead of a unique IP address) make this approach very complicated. Also, large number of signalling messages as proposed in this mechanism is not good for satellite networks as they consume the scarce and expensive satellite bandwidth.

Authors in [8] and [9] introduced Tree Morphing and Enhanced Tree Morphing (ETM) respectively, which are routing protocol adaptive to SSM source mobility. The concept of the source tree extension or elongation as the source moves from the previous designated multicast router (pDR) to new designated router (nDR) is not applicable in satellite scenario because the delivery tree rooted at the source in one GW cannot be extended to that same source when it moves to a different GW. This makes the fundamental design concept of these extensions not consistent with the nature of satellite networks.

SSM source handover notification approach proposed by authors in [10] suggested adding a new sub-option in the standard IPv6 destination binding option known as SSM source handover notification. During handover, the source after acquiring new IP address will notify receivers to subscribe to the new channel. The problems here are the large amount of signalling traffic over satellite air interface and the fact that some receivers may be unsynchronized to source handovers, leading to severe packet loss.

A mobile multicast source support for SSM in proxy mobile IPv6 domain has been proposed by authors in [11]. One of the drawbacks here is that there are no mechanisms to supress upstream forwarding to Local Mobility Anchor (LMA) [12] even when there are no receivers. Triangular routing is also a problem here when a mobile receiver and a source, all having different LMAs are attached to the same Mobility Access Gateway (MAG) [12]. In such a situation, the MAG has to forward traffic upstream to the corresponding LMA of the mobile source, which will tunnel the traffic to the corresponding LMA of the mobile receiver which then tunnels the traffic back to the same MAG for delivery to mobile receiver, causing waste of network resources in the whole domain. The fact that in proxy mobile IPv6 domain, the LMA is the topological anchor point for the addresses assigned to mobile nodes within the domain (i.e., packets with those addresses as destination are routed to the LMA), the role of the LMA and MAG does not fit well into a global interactive multi-beam satellite network with many Transparent/Regenerative Satellite Gateways [13], each having different IP addressing space.

This paper proposes a new solution consistent with the DVB–RCS/S2 satellite network specifications that supports SSM source mobility within the satellite network. The provision of solution to the problems of transparency and RPF without creating triangular routing paths and making use of encapsulation (tunnelling) are what make this approach unique. The solution is divided into two parts; support for receivers within the satellite network and those in terrestrial Internet.

III. Proposed Multicast Source Mobility Mechanism for SSM in Satellite Network

A. *Network Architecture*

Figure 1 shows the network architecture, where a mobile multicast source is present in beam 1 and the receivers are in beams 1, 2, 3 and 6. GW_A1 serves beams 1 and 2, GW_A2 and GW_A3 serve beams 3 and 4, respectively and GW_A4 serves beams 5 and 6.

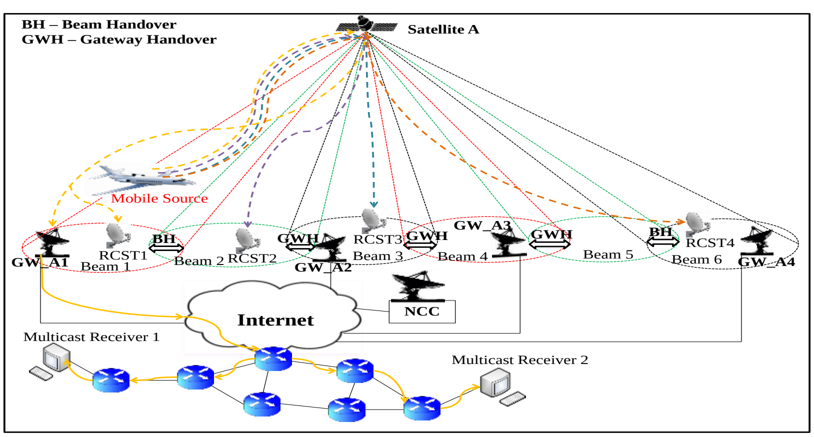

Figure 1. Mobile Source at Home Network (GW_A1)

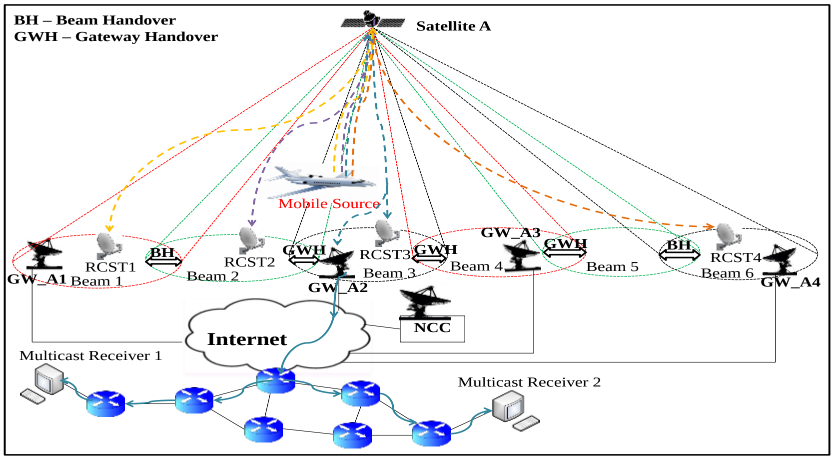

Figure 2. Mobile Source at Foreign Network (GW_A2)

The multicast receivers in the terrestrial network are connected through GW_A1. The mobile source sends out four identical streams of multicast traffic, each for one of the four beams that has interested receivers. This is because the satellite is a transparent one with no IP layer 3 capabilities on-board the satellite to replicate multicast traffic.

Figure 2 shows the mobile source now in beam 3 after successful handover. Here, the terrestrial SSM receivers are now connected through GW_A2 which is the serving gateway to the mobile source in beam 3. This illustrates how the multicast delivery tree to the terrestrial receivers changes whenever the mobile source changes its point of attachment to the satellite network from one satellite gateway to another.

B. *Source Adressing scheme*

According to the DVB specifications each GW has its own IP addressing space different from every other. This proposal leverages on the fact that each mobile Return Channel Satellite Terminal (mRCST), can be reserved a specific IP address under each GW. It is proposed that the IP addresses of the mRCST (in this case, mobile source) under various GWs are made known to the listening RCSTs/GWs as soon as they subscribe to the SSM. This can be made possible by associating the mRCST physical (MAC) address to a specific IP address as illustrated in Table 1.

TABLE I. MOBILE SOURCE IP ADDRESS UNDER EACH GATEWAY

Mobile RCST(Source)	Mac Address	IP Unicast Address			
		GW1	GW2	GW3	GW4
mRCST1	mac 1	a 11	a 12	a 13	a 14
mRCST2	mac 2	a 21	a 22	a 23	a 24
⋮	⋮	⋮	⋮	⋮	⋮
mRCSTn	mac n	a n1	a n2	a n3	a n4

It is assumed here for simplicity that there are 4 gateways under the control of the Network Control Centre (NCC). However, this can be easily extended. If this allocation can be pre-assigned by the NCC at the time of joining the multicast group, then this would remove the need for the use of tunnelling between GWs. Instead, native forwarding along the source-specific delivery tree throughout the network can be supported.

C. *Support for multicast receivers within the Satellite Network*

It is assumed here that:

- The transparent satellite has on-board multiplexing capability to provide connectivity between different beams provided at the physical layer and mainly responsible for forwarding MF-TDMA carriers or groups of carriers in an uplink beam to different downlinks beams.
- Each mRCST knows all its IP addresses under various GWs as described in the previous section.
- The NCC will act as the the Internet Group Management Protocol (IGMP) querier for the satellite network [13] and contains IP addresses of all mRCSTs under each GW in addition to its normal functionalities
- The NCC enables the establishment of point-to-multipoint connection between source and listening RCSTs/GWs.

The NCC acting as satellite IGMP querier keeps control of the multicast groups and also builds the SSM tree based on on-board connectivity between different beams. Periodically, the NCC sends out the Multicast Map Table (MMT) [14] to all multicast receivers. The MMT which contains the list of IP multicast addresses each associated with a specific Program Identifier (PID) enables listening RCSTs/GWs to receive multicast traffic from groups which

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they are members of. When the NCC receives an IGMP join report for SSM, it checks the source-list and if some sources are identified as mRCSTs, it will immediately respond with a unicast message to the RCST/GW which requested listening by stating that the multicast source is a mobile source, as well as giving out the source IP addresses under each GW (e.g., Mobile source; IP addresses: a11, a12, a13, a14). This message prepares the receiver to expect multicast traffic from any of these IP addresses knowing that it is coming from the same source, thus, solving the problem of transparency. For receivers on LAN behind RCSTs [14], the RCST acting as an IGMP Router and Querier on its user interface (i.e., interface towards the internal LAN) and an IGMP Host on the satellite interface, after receiving the mobile source details, will take up the role of notifying any interested user terminal in its LAN of the multiple IP addresses of the mobile source. The listening RCSTs' user interface delivers the traffic according to channel subscription (S, G) to user terminals.

D. Support for multicast Receivers on the Internet

It is proposed that all GWs in the Interactive Satellite Network (ISN) should be equipped with a new Multicast Mobility Management Unit (M3U) that is responsible for control plane signalling to provide support for mobility for multicast sources. This new M3U entity contains the following:

- A database of information regarding all mRCSTs in the entire ISN, each identified by its physical (MAC) address and the fixed IP addresses it has under each GW as shown in Table 1.
- A message chamber which can generate three new types of messages shown in Table II.

TABLE II. PROPOSED NEW MESSAGES

Message Name	Interface state message	Target GW message	Channel update message
Type	Unicast	Unicast	Multicast
Source	Serving GW	Target GW	Serving GW
Destination	Neighbouring GWs	Serving GW	All SSM Receivers in the Internet
Content	SSM reception interface state i.e., Multicast addresses, filtering mode and source list.	IP address of the Target GW	IP address of mobile source in target GW. Instruction to update channel subscription to new mobile source IP address
Purpose	To identify the mobile source in preparation for GW handover	To notify serving GW which neighbouring GW will be the target GW	For the Internet receivers to start building the new delivery tree to the target GW

When a GW receives the first IGMP join report for SSM, a service interface (socket; interface; multicast address; filter-mode; source-list) [15] is created against the interface that received the join report. While forwarding this join report to the NCC, the M3U as shown in Figure 3, checks the multicast source-list in the report against the data base containing the list of all mRCSTs. If some sources on the source-list are identified as mRCSTs, then the M3U of the serving GW will send the new proposed Interface State Message (ISM) to all neighbouring GWs. The neighbouring GWs extract the mobile sources (mRCSTs) from the source list after consulting the database in their M3U.

When the mobile source moves and a handover procedure is initiated by the NCC by sending the SNMP Set-Request message to the target GW, the target GW issues the new proposed Target GW Message (TGM) to the serving GW. The TGM enables the serving GW to identify which of its neighbouring GWs will be the target GW for the mobile source.With the knowledge of the target GW identity and upon consulting its database, the serving GW will then issue the Channel Update Message (CUM) to all SSM receivers in Internet/LAN.

It should be noted here that only the serving GW can reach all SSM receivers in the Internet since it is located at the root of the SSM delivery tree to the Internet. Upon reception of CUM by SSM receivers in the Internet, a new SSM delivery tree construction to the target GW is triggered as shown in Figure 2. Target GW issues IGMP join report to NCC as soon as it gets the updated channel subscription request (PIM Join) from Internet and at the same time, its M3U will issue ISM to all GWs neighbouring target GW in preparation for the next GWH. The target GW now becomes part of the mesh receivers within the satellite network described in section IIIC above as it assumes the responsibility of serving receivers in the Internet. This therefore makes the IP address changes during a GW handover transparent to all SSM recipients. Eventually, the old tree to old GW will be torn down as it becomes inactive (no traffic).

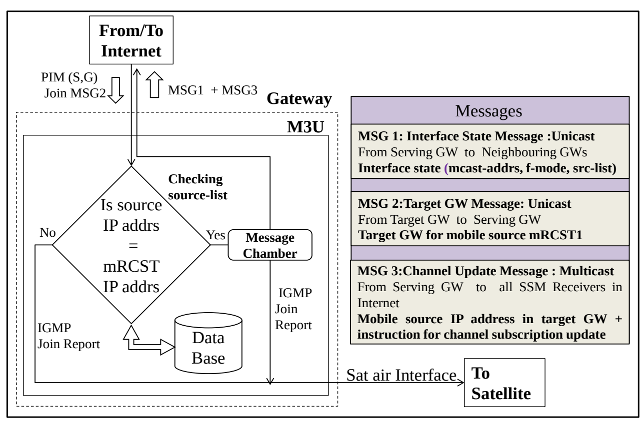

Figure 3. Multicast Mobility Management Unit (M3U)

E. Message sequence for multicast source mobility

Figure 4 shows the signalling sequence during GW handover.

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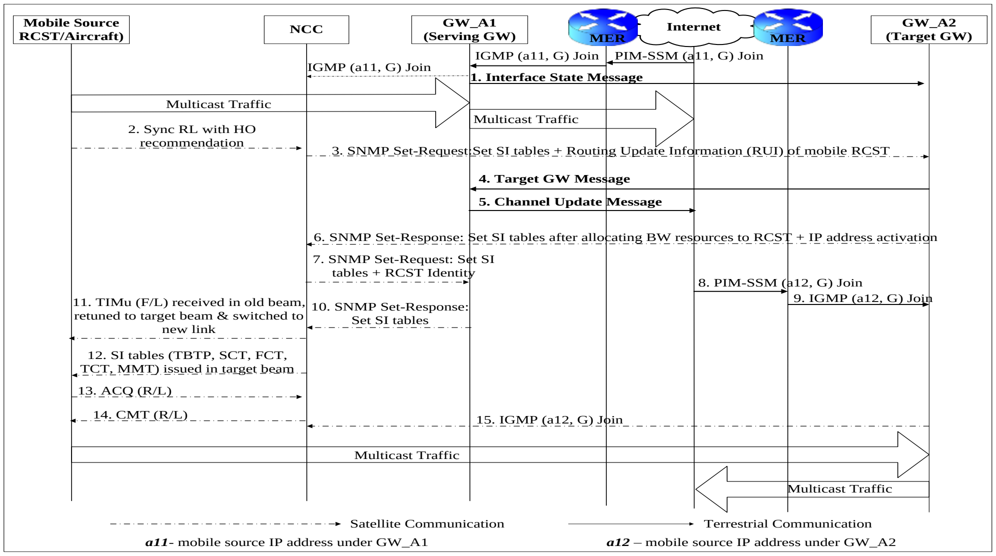

Figure 4. Signalling sequence at gateway handover

This signalling sequence contains the proposed new messages integrated into the standard GW handover signalling sequence given in [5]. Figure 4 is the detailed illustration of what is described in section IIID. From the signalling sequences in Figure 4, the sizes of the signalling messages determine the total time required to complete a GWH.

IV. GW HANDOVER PERFORMANCE EVALUATION

The messages sizes used in table III are derived from [16, 17] and [18]. It is assumed that the routing update information table (RUI) contains at least 100 bytes of routing data.

TABLE III. GW HANDOVER SIGNALLING MESSAGES SIZES

Messages	Packet Length (in Bytes)
Message 1 (containing at least 3 sources)	45
Synchronisation (SYNC) Burst	16
SNMP Set-Request: set SI tables + RUI	736
Message 2	28
Message 3	28
SNMP Set-Response: set SI tables	636
SNMP Set-Request: set SI tables + RCST Identity	640
PIM-SM Join	64
SNMP Set-Response: set SI tables + RCST Identity	640
TIM (Terminal Information Message)	35
SI Tables (TBTP, SCT, FCT, TCT, MMT)	152
ACQ (Acquisition Burst)	12
CMT (Correction Message Table)	30
IGMP Join	64

The time taken to transmit a single message between two relevant network entities over any given link under ideal conditions i.e., lossless conditions is given by (1) and the time required to send a message during handover relevant signalling entities under lossy conditions is given by (2).

$$T_{lossless} = T_{trans} + T_{prop} + T_{proc} \tag{1}$$

$$T_{total} = T_{lossless} + (T_{lossless} + T_{w}) \times \left[\frac{q}{1-q}\right] + T_{INT} \tag{2}$$

Where,

- T_{trans} = transmission delay = message size ÷ link bit rate.
- T_{Proc} = average processing time at any node. This is assumed to be 5 ms [18] for all nodes.
- T_{prop} = propagation delay due to the communication link.

$$T_{prop} = \begin{cases} T_{prop\_wireless} \\ T_{prop\_wired} \\ T_{INT} \end{cases} \tag{3}$$

-$T_{prop\_wireless}$ = propagation delay due to wireless link
-T_{prop_wired} = propagation delay due to wired link
- T_{INT} = propagation in the Internet. Since it is impossible to know the rout taken by the packet in the Internet with certainty, it is assumed to be 8 ms as suggested in [18].

- q = probability of a failure transmission over satellite.

The data rate in the satellite link is assumed to be 144Kbps [18] and the gateways are assumed to be using 100 Base-T Ethernet supporting a data rate of 100Mbps. The propagation speed in LAN Ethernet is assumed to be 2/3 the speed of light i.e., 2 x108m/s [18]. The distance between the gateway and the multicast edge router MER is assumed to be 4m.

Figure 5 shows that the total time required to complete GWH and to reconstruct the SSM delivery tree to target GW increases with increasing probabilities of failure. It should be noted that the new SSM tree construction starts when any receiver in the Internet issues the first IGMP/PIM –SSM join message to the target GW upon reception of channel subscription update message. It can be deduced from Figure 5 that for probabilities of failure 0% - 10%, the average time taken to complete:

- GWH with only mesh multicast support is 2.83 seconds
- GWH with mesh and terrestrial (internet) multicast support is 3.22 seconds
- New SSM delivery tree construction to target GW and the first IGMP reaching the NCC is 1.85 seconds.

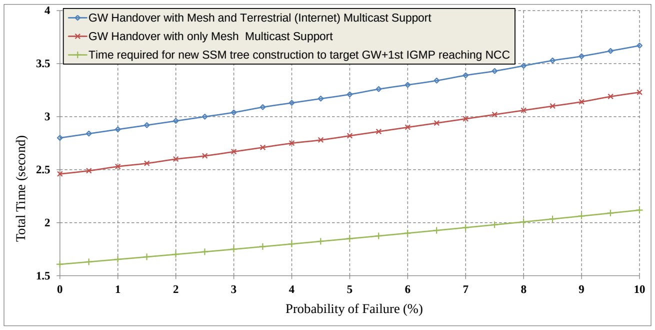

Figure 5. GW handover time delay at probabilities of failure 0% – 10%

Note should be taken of the fact in this proposal, no additional time delay (compared to the standard in [5]) is incurred for source mobility support for mesh receivers during GWH and that the actual time between switching links from serving GW to target GW is very small compared to the total GWH time shown above

V. CONCLUSION

IP multicast based applications are very important for satellite networks in order to share vital information between various receivers without the wastage of expensive satellite resources. Multicast sources that may move from one point of attachment to another will result in the breakage of the multicast tree. While some solutions to support multicast source mobility have been proposed for the internet, it was seen that these are not very suitable in a satellite network. This paper proposes a suitable solution for multicast source mobility in a multi-beam satellite network. It presents the network architecture and the proposed address management scheme. A new Multicast Mobility Management Unit (M3U) has been proposed within the GW along with three new control messages that provide support for mobility for multicast sources. The proposed solution has made it possible to solve the mobile multicast source transparency and RPF problems. Time delay analysis was carried out in order to evaluate the performance during the gateway handover. The results obtained from GWH performance evaluation above show that source mobility support for SSM has very little or no impact on handover latency on receivers within the satellite network.

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