TraSH-SN: A Transport Layer Seamless Handoff Scheme for Space Networks

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***Abstract*— The Internet Engineering Task Force has developed Mobile IP to handle mobility of Internet hosts at the network layer. Spacecrafts in space are analogous to mobile nodes in the terrestrial network. NASA has been experimenting with Mobile IP to handle handoffs in space networks. Mobile IP, however, suffers from a number of drawbacks such as high handoff latency, packet loss, and interoperability issues with network security solutions. In this paper, we describe `TraSH-SN`, a new Transport Layer Seamless Handover scheme for Space Networks, to handle handoffs in space networks. `TraSH-SN` utilizes multi-homing to achieve a seamless handoff of a spacecraft, and is designed to solve many of the drawbacks of Mobile IP. Various aspects, such as handoff, signalling, location management, data transfer, and security considerations of `TraSH-SN` are discussed, and its application to space networks is also outlined.**

I. Introduction

Spacecrafts communicate with ground stations on the earth and among themselves to carry data traffic. Depending on the altitude, satellites can be classified into three types: Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geosynchronous Earth Orbit (GEO). GEO satellites are stationary with respect to earth, but LEO and MEO satellites move around the earth, and are handed over between ground stations as they pass over different areas of the earth. This is analogous to mobile computers being handed over between access points as the users move in a terrestrial network. As a result, the National Aeronautics and Space Administration (NASA) has been studying the use of Internet protocols for space communications [1]. For example, the Global Precipitation Measurement (GPM) project is studying the possible use of Internet technologies and protocols to support all aspects of data communication with spacecraft [2]. The Operating Missions as Nodes on the Internet (OMNI) [3], [4] project at GSFC is not only involved in prototyping, but is also testing and evaluating various IP-based approaches and solutions for space communications. Other efforts in using Internet protocols for space communications have also been reported [5]. Some of these projects are also involved in hanodoffs in space networks. Such projects include OMNI [6], [3], Communication and Navigation Demonstration on Shuttle (CANDOS) mission [7], and the GPM project [8]. NASA has also been working with Cisco on developing a Mobile router [9]. It is also anticipated that Mobile IP will play a major role in various space related NASA projects such as Advanced Aeronautics Transportation Technology (AATT), Weather Information Communication (WINCOMM) and Small Aircraft Transportation Systems (SATS) [9].

Mobile IP (MIP) [10] is the standard proposed by the Internet Engineering Task Force (IETF) to handle mobility of Internet hosts for mobile data communications. For example, it enables a TCP connection to remain alive and receive packets when a mobile host moves from one point of attachment to another. MIP is based on the concept of Home Agent (HA) and Foreign Agent (FA) for routing of packets from one point of attachment to the next. During handoff from the HA to the FA, a mobile host (MH) registers with the FA, waits for the allocation of channels, and updates its location in the HA database.

While MIP is a widely accepted concept in both research and industry, MIP suffers from a number of problems, the most important ones identified to date include:

- High handoff latency [11]: A MH needs to complete the following three steps before it can receive forwarded data from the previous point of attachment:

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(i) discovering the new Care of Address (CoA), (ii) registering the new CoA with the HA, and (iii) forwarding packets from the HA to the current CoA. These give rise to high handoff latency for MIP.
- High packet loss rate [12], [13]: During the HA registration period, some or all of the packets destined to the MH's old CoA will be lost since the old point of attachment can not communicate with the MH during this period, nor does it know the new point of attachment of the MH.
- Inefficient routing [11]: In base MIP, large amount of data is routed to the HA, and then tunnelled to the MH. This wastes network resources and requires high processing power at mobile agents (HA and FA). This may give rise to scalability issues as the number of MHs managed by a HA increases. Moreover, the failure of a single HA may prevent a large number of mobile users from receiving forwarded packets from the HA unless a backup scheme like automatic HA discovery is used.
- Conflict with network security solutions [11]: Base MIP does not cooperate well when the HA is behind a firewall and the MH is outside the firewall, unless firewall transversal solution [14] is used. Moreover, base MIP has difficulty in the presence of a foreign network implementing ingress filtering, unless reverse tunnelling, where the HA's IP address is used as the exit point of the tunnel, is used to send data from the MH.

With only one CoA in MIP, the MH cannot communicate with the old mobile agent while the MH is registering with the new mobile agent. This restriction gives rise to *high handoff latency* and *high packet losses*. Even if the various proposed improvements [15], [16], [17], [18] for MIP are used, this fundamental restriction can not be overcome, since different MIP extensions still use only one interface for communication.

The question that naturally arises is: Can we find an alternative approach to network layer based solution for mobility support and to carry out handoffs that will be equally applicable for data communications in both terrestrial and space networks using multiple interfaces? Since most of the applications in the Internet are end-to-end, we have proposed and developed `TraSH-SN`, a transport layer based mobility solution as an alternative to MIP for handoffs.

The *objective* of this paper is to describe our proposed new scheme called Transport Layer Seamless Handover scheme for Space Networks (`TraSH-SN`) for supporting mobility, its design issues, and its suitability for space networks. The basic idea of `TraSH-SN` is to exploit multi-homing to keep the old path alive while setting up a new path, thus achieving a seamless handoff between adjacent subnets. It is based on the principle of decoupling registration, data transfer and handoff. One of the performance measures of a handoff scheme is the transport layer throughput. `TraSH-SN` lets the transport layer to handle the handoff, allowing the transport layer to integrate handoff with the transport layers functions to optimize its performance. A new IETF-standard transport protocol, called Stream Control Transmission Protocol (SCTP) [19], that has built in multihoming support will be used to illustrate the concepts of `TraSH-SN`. Although we illustrate `TraSH-SN` using SCTP, it is important to note that `TraSH-SN` can cooperate with normal IPv4 or IPv6 infrastructure without the support of Mobile IP. `TraSH-SN` has also a number of advantages such as easier deployment because of no change required in the Internet infrastructure, co-operation with Internet's security protocols, efficient utilization of network bandwidth due to the absence of tunnelling, etc.

The contributions of this paper can be outlined as follows:
- Propose and develop `TraSH-SN` that is expected to solve several problems faced by MIP in space networks. Here "seamless" means low latency and low packet loss.
- Illustrate the handoff procedure, signalling procedure and location management in `TraSH-SN` and compare them with MIP.
- Discuss handoff scenario in space networks, and the application of `TraSH-SN` in such an environment.

The rest of this paper is structured as follows: Sec. II summarizes handoff architectures in space environments. Sec. III gives a brief introduction to SCTP and its multihoming feature. Sec. IV describes in detail the steps and signalling procedures in `TraSH-SN`, followed by suitability of `TraSH-SN` for space networks in Sec. V. `TraSH-SN`'s location management and data transfer paths are described in Sec. VI. Vertical handoffs between heterogeneous networks, such as between wireless LANs, cellular, and wireless networks is presented in Sec. VII. Finally, concluding remarks are presented in Sec. VIII.

II. Handoffs in a Satellite Environment

LEO satellite systems have some important advantages over GEO system as the component of next generation Internet. These include lower propagation delay, lower power requirements both on satellite and user terminal, more efficient spectrum allocation due to the frequency reuse between satellites and spotbeams. However, due to the non-geostationary characteristics and high speed movement of LEO satellites, the mobility management in LEO is much more challenging than in GEO or MEO system. In this section, we will discuss both link layer and network layer handoff that are required to support continuous communication over a LEO satellite system.

A. *Link Layer Handoff*

Handoff events in LEO systems can be classified as follows [20]:

1) *Inter-satellite handoff*: This kind of handoff happens when the end user's attachment point is changed from one satellite to another. Since this change will affect the routing of the ongoing session and the resource allocation of the satellites, the research efforts in this area focus on algorithms for the dynamic rerouting of a connection and the admission control of handoff calls to ensure QoS requirements [21], [22], [23], [24].
2) *Link handoff*: When a LEO satellite passes over the polar area, the inter-satellite links (ISL) to the neighbor satellite are switched off temporarily. The ongoing connections utilizing these links have to be transferred to other links, causing link handoffs. A number of previous research have attempted to reduce the signaling overhead and blocking probability caused by link handoffs [25], [26].
3) *Spotbeam handoff*: This kind of handoff happens when the user cross the boundary between the spotbeams of a satellite; it can be regarded as an intra-satellite handoff. Spotbeam handoffs occur frequently (every 1-2 minutes) since the coverage area of a specific spotbeam is relatively small. The research in this area mostly concentrate on admission control algorithms and schemes for reducing the blocking rate for handoff connection and new connections [27], [28].

We regard them as link layer handoff in general, since these handoffs involve the change of one or more links between the two communicating endpoints, while not necessarily changing the IP address of the endpoints. After a link layer handoff, it is possible that a network layer handoff is also required, which will be discussed in Sec. II-B

B. *Network Layer Handoff*

If one of the communicating endpoint (either satellite or user terminal) changes its IP address due to the movement of satellite or mobile user, a network layer handoff is required to migrate the connection of higher level protocol (e.g. TCP, UDP, or SCTP) to the new IP address. In this section, two scenarios requiring network layer handoff in a satellite environment are identified.

1) *Satellite as a router* (Fig 1): When a satellite does not have any onboard equipment which generates or consumes data, but is equipped with on board IP routing devices, the satellite acts as a router in the Internet. Hosts are handed over from one satellite to another as the hosts come under the footprint of different satellites as they circle the earth. Fixed Host/Mobile Host (FH/MH) need to maintain a continuous transport layer connection with the correspondent node (CN) while their attachment point change from Satellite A to Satellite B. Different satellites or even different spotbeams within a satellite can be assigned with different IP network addresses. In such a case, IP address change occurs during an inter-satellite handoff, thus requiring a network layer handoff. For very highly dense service areas, the spot-beam handoff may also require a network layer handoff. Previous research [29], [30] have used Mobile IPv6 to support mobility management in LEO system. In such a case, the FH/MH and Location Manager are mapped to the Mobile Node and Home Agent, respectively, of Mobile IP.

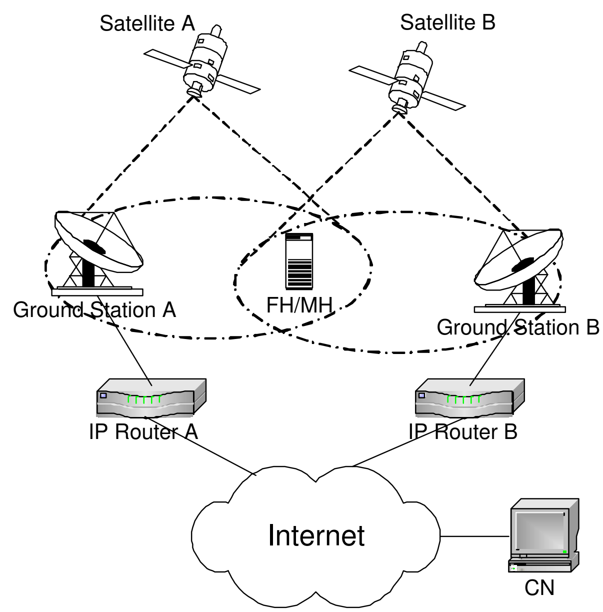

Fig. 1. User handoff between satellites.

2) *Satellite as a mobile host* (Fig 2): When a satellite has on board equipment (such as earth and space observing equipment) which generates data and are transmitted to workstations on Earth or it receives control signal from the control center, the satellite acts as the endpoint of the communication, as shown in Fig. 2. In this figure, although the satellite's footprint moves from ground station A to B, the satellite should maintain continuous transport layer connection with its corespondent node (CN). If the IP address of the satellite has to be changed when it is handed over to ground station B, a network layer handoff has to be performed.

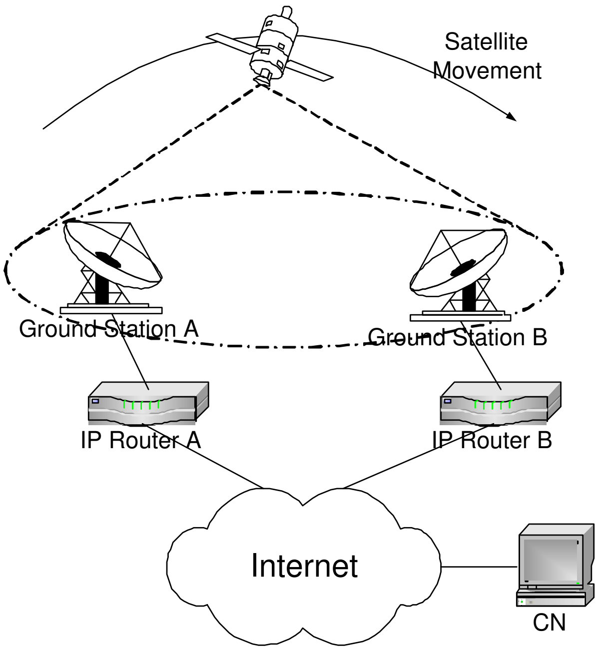

Fig. 2. Satellite handoff between ground stations.

III. Brief Introduction to SCTP and Multi-homing

In this section, we describe the salient features of SCTP in order to help the reader understand `TraSH-SN` (described in Sec. IV, which uses SCTP because of its built-in support for multihoming. SCTP is a new reliable transport layer protocol which is being standardized by the IETF [19]. The design of SCTP absorbed many of the strengths of TCP, such as the window based congestion control, error detection and retransmission, that led to its success during the explosive growth of the Internet. Moreover, SCTP incorporated several new features, such as multi-streaming and multi-homing, that are not available in TCP. Due to its new attractive features, SCTP has recently received much attention from the research community, and has become one of the hot topics in networking technology [31], [32], [33].

Multi-homing allows an association between two end points to span across multiple IP addresses or network interface cards. An example of SCTP multi-homing is shown in Fig. 3, where the two end points are connected through two wireless access networks. The correspondent node (CN) is single-homed, while the Mobile Host (MH) is multi-homed. The MH can use one or two interface cards as long as the two IP addresses can be bound into the association. One of the MH's IP addresses is designated as the primary destination address for the transmission of data by the CN, while the other one can be used as a backup in the case of failure of the primary address, or when the upper layer application at the CN explicitly requests the use of the backup address.

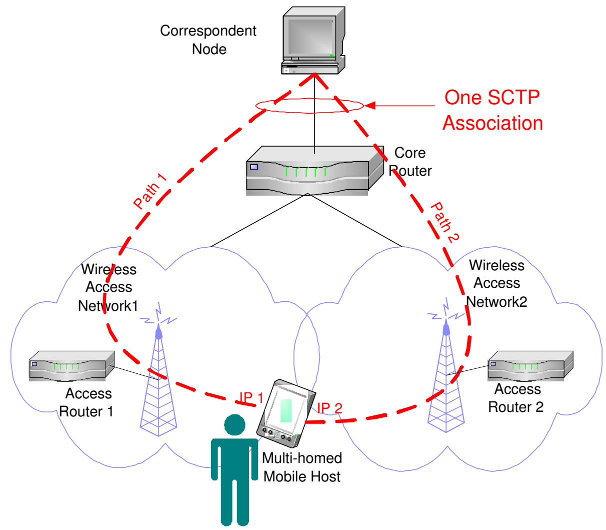

Fig. 3. An SCTP association with multi-homed mobile host.

Retransmission of lost packets can also be performed over the backup address. SCTP's built-in support for multi-homed endpoints is especially useful in environments that require high-availability applications, such as SS7 signaling transport. A multi-homed SCTP association can speedup the recovery from link failures without interrupting the data transfer [34].

IV. Handoff in `TraSH-SN`

In this section, we discuss the details of `TraSH-SN` which will be helpful in understanding the mapping of `TraSH-SN` to space networks in Sec. V. We assume that the direction of traffic flow is from the CN to MH, which corresponds to services like file downloading or web browsing by mobile users. In this section, we outline `TraSH-SN`'s signalling procedure during the handoff process. The complete handoff procedure can be divided into five parts which are described below. The main idea of `TraSH-SN` is to exploit multi-homing to keep the old data path alive until the new data path is ready to take over the data transfer, thus achieve low latency, low loss handoff between adjacent subnets.

A. STEP 1: Obtain new IP address

Referring to Fig. 3, the handoff preparation procedure begins when the MH moves into the overlapping radio coverage area of two adjacent subnets. Once the MH receives the router advertisement from the new access router (AR2), it should initiate the procedure of obtaining a new IP address (IP2 in Fig. 3). This can be accomplished through several methods: DHCP, DHCPv6, or IPv6 Stateless Address Autoconfiguration

(SAA) [35]. The main difference between these methods lies in whether the IP address is generated by a server (DHCP/DHCPv6) or by the MH itself (IPv6 SAA). For cases where the MH is not concerned about the its IP address, but only requires the address to be unique and routable, IPv6 SAA is a preferred method for `TraSH-SN` to obtain a new address since it significantly reduces the required signalling time.

B. STEP 2: Add IP addresses to association

When the SCTP association is initially setup, only the CN's IP address and the MH's first IP address (IP1) are exchanged between CN and MH. After the MH obtains another IP address (IP2 in STEP 1), MH should bind IP2 into the association (in addition to IP1) and notify CN about the availability of the new IP address.

SCTP provides a graceful method to modify an existing association when the MH wishes to notify the CN that a new IP address will will be added to the association and the old IP addresses will be probably be taken out of the association. The IETF Transport Area Working Group (TSVWG) is working on the "SCTP Address Dynamic Reconfiguration" Internet draft [36], which defines two new chunk types (ASCONF and ASCONF-ACK) and several parameter types (Add IP Address, Delete IP address, Set Primary Address, etc.). This option will be very useful in mobile environments for supporting service reconfiguration without interrupting on-going data transfers.

In `TraSH-SN`, MH notifies CN that IP2 is available for data transmission by sending an ASCONF chunk to CN with parameter type set to 0xC001 (Add IP Address). On receipt of this chunk, CN will add IP2 to its local control block for the association and reply to MH with an ASCONF-ACK chunk indicating the success of the IP addition. At this time, IP1 and IP2 are both ready for receiving data transmitted from CN to MH.

C. STEP 3: Redirect data packets to new IP address

When MH moves further into the coverage area of wireless access network2, data path2 becomes increasingly more reliable than data path1. CN can then redirect data traffic to the new IP address (IP2) to increase the possibility of data being delivered successfully to the MH. This task can be accomplished by the MH sending an ASCONF chunk with the Set-Primary-Address parameter, which results in CN setting its primary destination address to MH as IP2.

The critical questions here are three-fold: (1) What kind of information should be used to trigger Set-Primary-Address, Layer 2, Layer 3 or Layer 4 handoffs? (2) Who initiates Set-Primary-Address: CN or MH? (3) When is the right time to execute Set-Primary-Address? The answers to questions (2) and (3) depend largely on the answer to question (1). If MH can utilize the information from Layer 2, such as radio link Signal/Noise Ratio (SNR), Bit Error Rate (BER), or available bandwidth, MH has much more information than CN about whether the primary data path should be switched over to the new path. To compensate for the transmission/propagation delay from MH to CN, the MH can send the ASCONF chunk predictively at a time which is RTT/2 before the optimal switchover time. One disadvantage of this method is that it requires cross-layer communication in the protocol stack, which may result in difficulties in protocol deployment. If Layer 2 information is not available to MH, CN and MH should have the same knowledge about the link status. In this case, it may be preferable to let CN initiate the Set-Primary-Address by observing the packet loss pattern over the old data path; this will have the advantage of reducing the handoff latency by RTT/2.

D. STEP 4: Updating the Location manager

`TraSH-SN` supports location management by employing a location manager that maintains a database which records the correspondence between MH's identity and current primary IP address. MH can use any unique information as its identity, such as the home address (as in MIP), domain name, or a public key defined in the Public Key Infrastructure (PKI).

Following our example, once the Set-Primary-Address action is completed successfully, MH should update the location manager's relevant entry with the new IP address (IP2). The purpose of this procedure is to ensure that after MH moves from the wireless access network1 into network2, further association setup requests can be routed to MH's new IP address IP2. This update has no impact on existing active associations.

We can observe an important difference between `TraSH-SN` and MIP: the location management and data traffic forwarding functions are coupled together in MIP, whereas they are *decoupled in* `TraSH-SN` *to speedup handover and make the deployment more flexible*.

E. STEP 5: Delete or deactivate obsolete IP address

When MH moves out of the coverage of wireless access network1, no *new* or *retransmitted* data packets should be directed to address IP1. In `TraSH-SN`, MH can notifies CN that IP1 is out of service for data transmission by sending an ASCONF chunk to CN with parameter type set to 0xC002 (Delete IP Address). Once received, CN will delete IP1 from its local association control block and reply to MH with an ASCONF-ACK chunk indicating the success of the IP deletion.

A less aggressive way to prevent CN from sending data to IP1 is for the MH to advertise zero receiver window (corresponding to IP1) to CN [37]. This will give CN an impression that the interface (on which IP1 is bound) buffer is full and can not receive any more data. By deactivating, instead of deleting the IP address, TraSH-SN can adapt more gracefully to MH's zigzag (often referred to as ping pong) movement patterns, and reuse the previously obtained IP address (IP1) as long as the lifetime of IP1 has not expired. This will reduce the latency and signalling traffic that would have otherwise been caused by obtaining a new IP address.

F. Timing diagram of TraSH-SN

Fig. 4 summarizes the signalling sequences involved in TraSH-SN. Here we assume IPv6 SAA and MH initiated Set-Primary-Address. Timing diagrams for other scenarios can be drawn similarly, but are not shown here because of space limitations. In this figure, the numbers

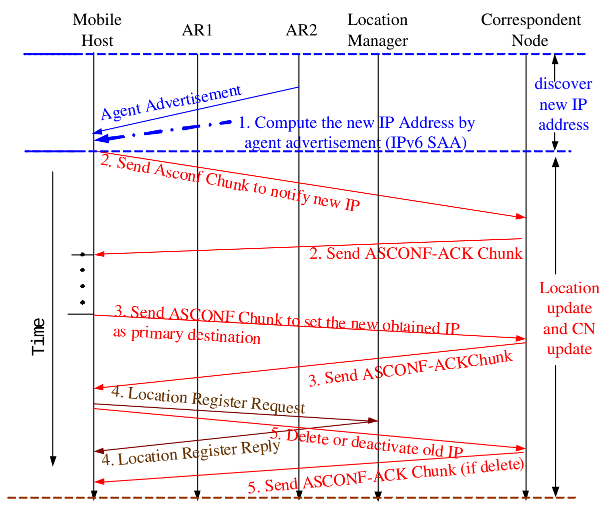

Fig. 4. Timeline of TraSH-SN.

before the events correspond to the step numbers in Sec. IV-A to IV-E, respectively.

V. Suitability of TraSH-SN for Space Environment

Having described handoffs in space networks and our proposed TraSH-SN scheme in Secs. II and IV, respectively, we describe below the mapping of TraSH-SN into a space handoff scenario, using satellites as examples of spacecrafts.

1) *Satellite as a router:* The research result of [38] showed that the mean number of available satellites for a given FH/MH is at least two for latitudes less than 60 degrees. This means the FH/MH is within the footprint of two satellites most of the time, which makes TraSH-SN very attractive for handoff management to reduce packet loss and handoff latency. The procedure of applying TraSH-SN in this handoff scenario is rather straightforward; we just need to map the FH/MH and satellites in Fig. 1 to the MH and access routers, respectively, in the TraSH-SN scheme (see Fig. 3) as given below:

- *Obtain new IP*: When FH/MH receives advertisement from Satellite B, it obtains a new IP address using either DHCP, DHCPv6, or IPv6 Stateless Address Autoconfiguration.
- *Add new IP address to the association*: FH/MH binds the new IP address into the association (in addition to the IP address from Satellite A domain). FH/MH also notifies CN about the availability of the new IP address by sending an ASCONF chunk [36] to the CN with parameter type as "Add IP Address".
- *Redirect data packets to new IP address*: CN can redirect data traffic to the new IP address from Satellite B to increase the possibility of data being delivered successfully to the FH/MH. This task can be accomplished by sending an ASCONF chunk with the Set-Primary-Address parameter to CN, which results in CN setting its primary destination address to FH/MH as the new IP address.
- *Updating the Location manager*: TraSH-SN supports location management by employing a location manager that maintains a database which records the correspondence between FH/MH's identity (such as domain name) and current primary IP address. Once the Set-Primary-Address action is completed successfully, FH/MH should update the location manager's relevant entry with the new IP address. The purpose of this procedure is to ensure that after FH/MH moves from the footprint of Satellite A into Satellite B, further association setup requests can be routed to FH/MH's new IP address.
- *Delete or deactivate obsolete IP address*: When FH/MH moves out of the coverage of satellite A, FH/MH notifies CN that its IP address in Satellite A domain is no longer available for data transmission by sending an ASCONF chunk to CN with parameter type "Delete IP Address".

In a satellite environment, FH/MH can predict the movement of Satellites A and B quite accurately due to the fixed movement track of the satellites. This capability will make the decision on the time to perform the set primary to the new IP address, and the time to delete the old IP address much easier than in cellular networks, where the user mobility is hard to predict precisely.

2) *Satellite as a mobile host:* In this case the satellite and IP Router A/B (see Fig. 2) will be mapped to the MH and access routers, respectively, in `TraSH-SN`. In order to apply `TraSH-SN`, there is no special requirement on the Ground Stations A/B and IP routers A/B in Fig 2, which will ease the deployment of `TraSH-SN` by not requiring to change the current Internet infrastructure. The procedure of applying `TraSH-SN` in this case is similar to the previous case (where the satellite acts as a router) if we replace the FH/MH by the satellite here, and replace Satellites A/B as IP routers A/B here.

   Since a satellite can predict its own movement track, it can contact Ground Station B while it is still connected to Ground Station A. There may be multiple new Ground Stations available to choose from due to the large footprint of satellites. The strategy for choosing a Ground Station can be influenced by several factors, such as highest signal strength, lowest traffic load, and longest remaining visibility period.

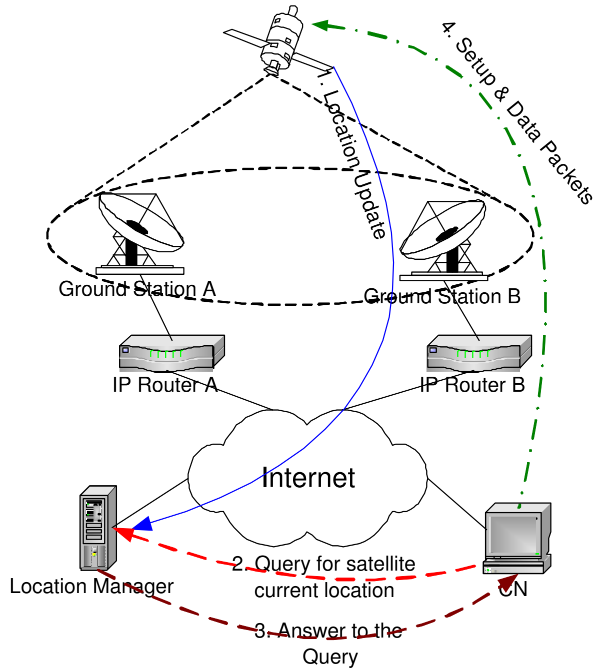

Fig. 5. Location management in `TraSH-SN`.

VI. Location Management and Data Transfer Path in `TraSH-SN`

As mentioned in Sec. IV-D, `TraSH-SN` requires a location manager for maintaining a database of the correspondence between MH's identity and its current primary IP address. In this section, we describe `TraSH-SN`'s location management and the data path between CN and MN.

A. Location management

Unlike MIP, the location manager in `TraSH-SN` is not restricted to the same subnet as mobile host's home network (in fact, `TraSH-SN` has no concept of home or foreign network). It should be emphasized that this will make the deployment of `TraSH-SN` much more flexible and easier than MIP. When a location manager is used, the location management can be done in the following sequence as shown in Fig. 5. Here we use the handover scenario, where the satellite acts as the mobile host as described in Sec. II-B, to illustrate the location management procedure. We do not show the scenario where satellite acting as router here since they are very similar.

1) The satellite updates the location manager with the current primary IP address.
2) When CN wants to setup a new association with the satellite, CN first sends a query to the location manager with satellite's identity (home address, domain name, or public key, etc.)
3) Location manager replies to CN with the current primary IP address of the satellite.
4) CN sends an SCTP INIT chunk to satellite's new primary IP address to setup the association.

If we use domain name as the satellite's identity, then we can merge the location manager into a DNS server. The idea of using a DNS server to locate mobile users can be traced back to [39], and can be implemented using Dynamic DNS updates [40]. The advantage of this approach is its transparency to existing network applications that use domain name to IP address mapping.

Since MIP requires that the location management entity must reside on the HA, this location manager (DNS server) based method is not applicable to MIP. In contrast to MIP, `TraSH-SN` *decouples location management from data traffic forwarding*, and hence can use DNS server based location management. An Internet administrative domain can allocate one or more location servers for its registered mobile users. Compared to MIP's requirement that each subnet must have a location management entity (HA), `TraSH-SN` can reduce system complexity and operating cost significantly by not having such a requirement. `TraSH-SN`, however, requires the satellite to provide the IP address of the location manager when it publishes its identity.

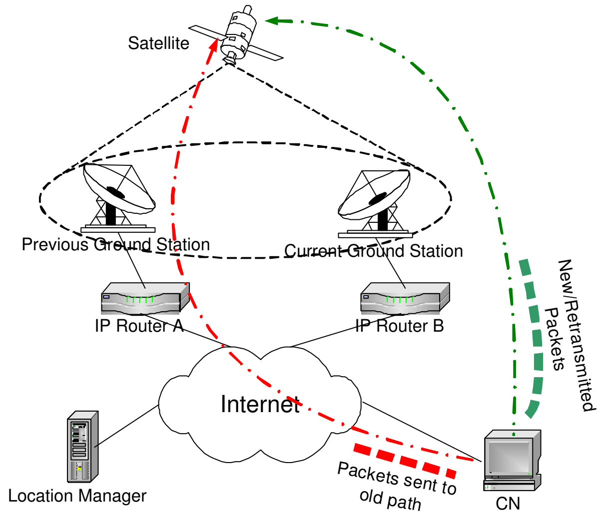

Fig. 6. Data transfer path after a `TraSH-SN` handoff.

B. Data transfer path

The data transfer path after a `TraSH-SN` handoff is illustrated in Fig. 6. Here also, we use the handover scenario where the satellite acts as the mobile host, as described in Sec. II-B, to illustrate the data path. The difference between `TraSH-SN` and MIP is that `TraSH-SN` sends data packets directly to the satellite instead of going through the HA. This eliminates the infamous triangular routing problem encountered in Base MIP. Note that, in `TraSH-SN`, the retransmitted packets (due to packets lost during the handoff) from CN should also be directed to the satellite's new IP address since the old IP address is very likely unreachable. In contrast to Mobile IP, there is no Home or Foreign agents in `TraSH-SN`. `TraSH-SN`, however, requires a location manager for the CN to locate the current position of the satellite when a new association setup is initiated by the CN.

VII. Vertical Handoff Between Heterogeneous Technologies

Different types of access network technologies can be integrated to give mobile users a transparent view of the Internet. Handoff is no longer only limited to between two subnets in Wirless LAN (WLAN), or between two cells in a cellular network (horizontal handoff). In the future, mobile users will expect seamless handoff between heterogeneous access networks (vertical handoff).

MIP operates in Layer 3 and is independent of the underlying access network technology. Although it can be used in a heterogeneous environment, there are some disadvantages in using Mobile IP for vertical handoffs [41], such as complexity in routing, high signaling overhead, significant delay especially when CN is located in foreign network, difficulty in integrating QoS protocols such as RSVP with triangular routing and tunnelling.

`TraSH-SN` is well suited to meeting the requirements of vertical handoff. Fig. 7 illustrates the use of `TraSH-SN` to perform vertical handoffs from WLAN to a cellular network, and then to a satellite network. The multi-homed mobile host in `TraSH-SN` is equipped with multiple interface cards that can bind IP addresses allocated from different kinds of wireless network access technologies.

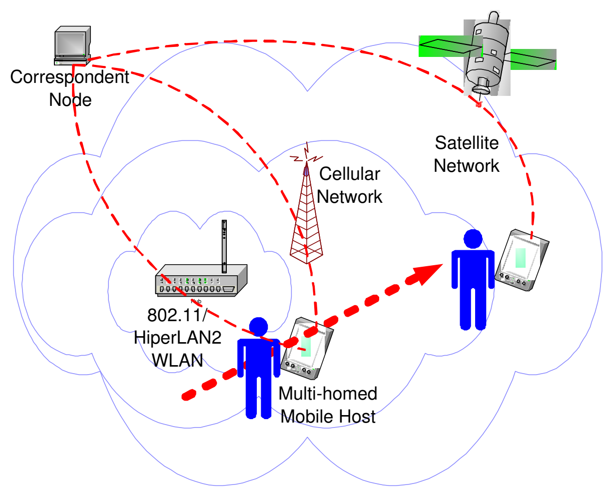

Fig. 7. Vertical handoff using `TraSH-SN`.

VIII. Conclusions

We have described our proposed new handoff scheme called Transport Layer Seamless Handover scheme for Space Networks (`TraSH-SN`) for supporting mobility in the Internet. We have also described the various types of handoffs that can occur in space networks and how `TraSH-SN` can be used to manage those handoffs in the space environment. We have shown that various components of `TraSH-SN` can be directly mapped to the architectural elements of the space handoff scenario. We conclude that `TraSH-SN`, with its many advantages over Mobile IP, is very suitable for managing handoffs in space networks. We have designed `TraSH-SN` in such a way that it will be applicable not only in space networks but can also be used for handoffs in Wireless LANs and cellular networks [42], [43]. This is in-line with NASA's objective of developing technologies which can be used in a wide range of applications to enable them to enjoy the research and development efforts of commercial vendors.

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