Handover Schemes for QoS guarantees in LEO-satellite ATM Networks

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Abstract

In the paper, we present effects of the mobility on QoS provisioning in multi-hop low earth orbit (LEO) satellite ATM networks and the necessity of the inter-satellite handover. Based on the LEO-satellite ATM network characteristics, different feasible inter-satellite handover schemes are proposed regarding to QoS handover requirements. The combination of the schemes is suggested as an efficient handover management scheme for LEO-satellite ATM networks. In addition, handover protocols are described in terms of signaling flows and control sequences. Finally, several performance metrics are evaluated by simulation under studied traffics and a system configuration.

1. Introduction

In the next generation of wireless communication systems, satellites will play an key role for providing global communication services. Conventional satellites operate in the geostationary orbit (GEO) with the significant drawback of long propagation delay, which badly impacts to multimedia services or TCP/IP-based data services. For that reasons, there is a strong interest in deploying so-called low earth orbit (LEO) satellites, which with respects to GEO satellites, have a lower orbit altitude (typically between 500 km and 1500 km), exhibit lower propagation delay and have terminal power consumption. Different LEO-satellite systems have been designed and developed to support and to supply global mobile communication, providing voice and low-rate data services. The next-generation of LEO satellite networks will provide broadband multimedia services, e.g. Teledesic planed to operate in 2003. The future satellite networks would provide fast packet switching such as in Teledesic or ATM on-board switching [1, 2].

One of the most important and challenging problems facing the next-generation LEO satellite system will be that of mobility management. Mobility management supports mobile terminals, allowing users to roam while simultaneously offering them incoming calls and supporting calls already in progress. Mobility management consists of two components: location management and handover management, providing the different tasks to support user mobility. In the paper, handover management schemes, which have to satisfy QoS requirements of ongoing connections with different service categories, are investigated. The remainder of this paper is organized as follows: in the next section, a brief description of LEO-satellite ATM networks and QoS handover issues are presented. Different feasible handover schemes for the networks are given and discussed in section 3. In section 4, handover protocols for the schemes are then described and performance metrics are evaluated. Solutions for QoS guarantees are also discussed here. A conclusion is drawn and topics for further investigation are given in the last section.

2. Issues of handover management in LEO satellite ATM networks

Satellite ATM network issues such as architecture and protocol layer models have been investigated in different research studies [1, 2]. In Fig. 1, a LEO-satellite network architecture with ATM-based on board switching, on-board processing and inter-satellite links (ISL) is presented. The satellites are mobile ATM switching nodes in the sky having mobility enhancement functions [2]. A satellite user subscribes with the satellite network service provider and can be a mobile or fixed located user. A non-satellite user subscribes to other networks. Equipped with the satellite adaptation unit (SAU), it can be served when it moves to the satellite covered areas. Both types of customers are directly connected to one of the mobile satellite nodes covering their location. Other customers of the satellite networks can be private networks, which are located in remote areas. The networks with earth stations (ES) interconnect to the rest of the world through the satellite network.

Generally, gateway earth stations (GES), gateways for short, are the interface between satellite networks and the terrestrial networks using an interworking unit (IWU). The procedures implemented in the GES are call-setup, billing, registration, etc. The connections between satellite users

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and terrestrial users must be handled by gateways [3, 4]. For connections between satellite users, the gateway only acts during the setup process. Thereafter the end-to-end connection is transferred through the space segment.

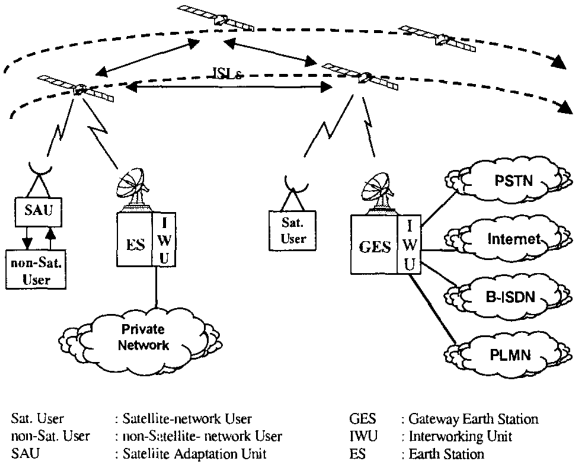


Figure 1. Architecture of LEO-satellite ATM network

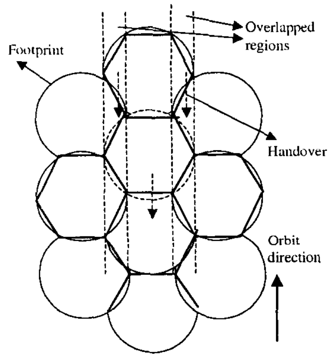


Figure 2. Inter-satellite handover

Handovers in LEO satellite networks can be classified as follows:

- ➢ Connection handover: When a satellite moves in its orbit, its coverage area (so-called *footprint)*, which may include multi-spotbeams, moves on the surface of the earth. Therefore, a connection between ground terminal and satellite has to be transferred from one beam to another beam in the same satellite, so called *Intra-satellite handover*, or between different satellites, so called *Inter-satellite handover* [5].
- ➢ Link handover: When the connectivity pattern of the network changes, the ongoing connection passing an ISL that is switch-off need to be rerouted. This type of handover is referred to as link handover.

Both connection and link handovers have certain impacts on QoS provisioning. Link handover is not considered in the paper. As shown in Fig. 2, the motion of satellites causes moving footprints. Therefore, the connection between ground user and serving satellite needs to be handed over from one satellite to another although the ground users can be fixed located. Inter-satellite handover occurs frequently, especially when the user is located in the overlapping area. Another reason for frequent inter-satellite handover is that for providing broadband services, the number of satellites in the constellation should be increased, thus decreasing the footprint size. Several effects on QoS occur due to the connection handover:

- Lost cells: When a connection is switched from one satellite to a new satellite, cells still being buffered in the old satellite, would be discarded. For loss sensitive services such as data, lost cells will reduce the throughput especially for TCP connections. Therefore, reducing the number of lost cells is an important task of handover schemes for LEO-satellite ATM networks.
- Delay and delay variation: Due to long propagation delays occurred in the satellite network, the handover process would cause a long delay and delay variation. These would badly affects to delay-sensitive services such as voice and video. For that reason, handover schemes also have to be able to support such services.

When inter-satellite handover occurs, the new path needs to be re-established while preserving the QoS requirements. Due to frequent inter-satellite handovers, a high number of re-routing attempts can cause a high signaling load. An efficient handover scheme has to reduce the number of re-routing attempts as much as possible. In the next section, we will propose different feasible handover schemes, which are designed based on the satellite network characteristics and QoS requirements of different service categories. The schemes also aim to reduce amount of signaling loads and handover time.

3. Inter-satellite handover schemes for QoS handover guarantees

A original path is considered as a set of satellites P{S_s, S_{i1}, S_{i2}...S_{in}, S_D} where S_s is the source satellite, S_{ij} is the intermediate satellite jth in the path and S_D is the current destination satellite. The parameters of a connection path include the end-to-end delay, the amount of required bandwidth etc., which satisfies QoS of the ongoing connection. In the following, different QoS handover schemes for LEO-satellite ATM networks are described for connections between a satellite user and a terrestrial user. For connections between two satellite users, the schemes are also applicable.

In Fig. 3.a, the path-augmentation handover scheme is presented for the case that the new destination satellite S'_D (Next-Sat) is one of the intermediate nodes in the original path, i.e. $S'_D = S_{ij}$ with $S_{ij} \in \{S_{i1}, S_{i2}...S_{in}\}$. Therefore, the original virtual circuit (VC) is not necessary to be re-established but can be augmented. The main advantage of the path-augmentation scheme is the reduced handover processing time, QoS guarantees of the new connection path, and especially reduced end-to-end delay due to the smaller number of hops.

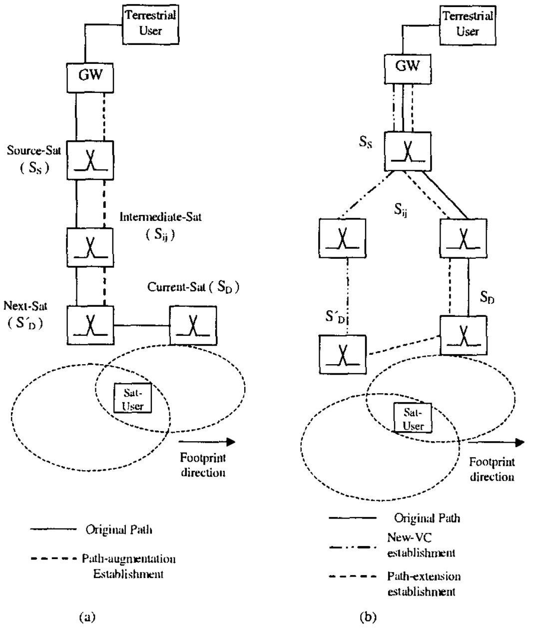


Figure 3. (a) Path-augmentation handover scheme & (b) New-VC establishment and path-extension handover schemes

In Fig. 3.b, we propose two different schemes for the case that S'_D is not an intermediate node in the original virtual circuit (VC).

➢ Path-extension scheme: The scheme is proposed when it is possible to create the new VC by extending the original VC with the new end-node is the satellite S'_D. The path-extension scheme also reduces the handover processing time. The disadvantage is that the delay of the connection will increase due to a higher number of hops. However, if the extended path still satisfies the delay requirement of the connection, path-extension is an efficient scheme for frequent handovers. For data services, which are not delay sensitive, path-extension could be the most suitable inter-satellite handover scheme.

➢ New-VC establishment scheme: The scheme is proposed for the case that when handover occurs, the original VC is not possible to be extended or augmented. New VC from the source satellite to the new destination satellite has to be re-established. The new-VC establishment scheme causes a long handover process and a high amount of signaling. Re-routing the end-to-end path takes a longer time than either the augmentation or the extension of the path. However, the scheme is useful and necessary for LEO satellite networks, especially for the case, that S'_D and S_D are located in counter-rotating orbits, which are the first and the last orbit [4] as either the augmentation or the extension of path is not possible.

In LEO-satellite ATM networks, different classes of services are provided while handover is essential and unavoidable. To support QoS handover guarantees of multi-service provision, the most efficient handover management scheme should be a combination of the proposed schemes. For example, if the service type of the ongoing connection is loss sensitive, path-extension is the favorable scheme because a prolonged path does not cause bad effects to the QoS. For delay sensitive services, the path-augmentation scheme is the most suitable. The path-extension scheme is also suitable for such services when the end-to-end delay is still below a given bound. Beside that, the new-VC establishment scheme is essential when an extended path does not satisfy the QoS requirements. In the next section, signaling and control sequences for the schemes are described, followed by different performance results obtained by simulation.

4. Handover protocols

4.1 Signaling flows and control sequences for proposed handover schemes

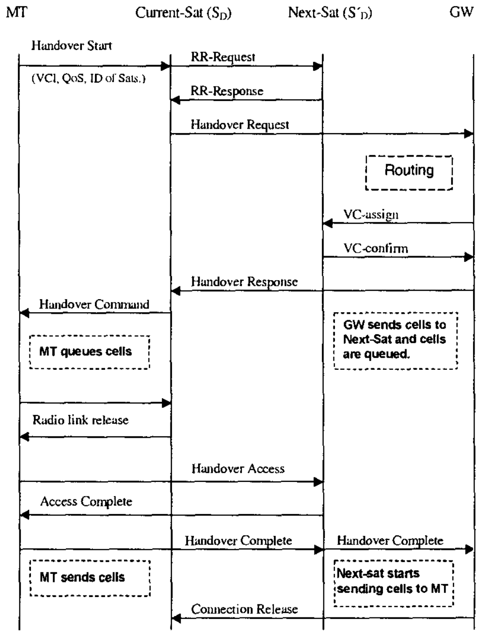


Figure 4. New-VC establishment handover protocol

The protocol for the new-VC establishment handover scheme showing in Fig. 4 is described in terms of signaling flow and control sequence as follows:

- Handover Start: This message, which contains QoS requirements, the original virtual circuit identifier (VCI) of the ongoing connection and the ID of the new satellite, is sent from the MT to the satellite S_D to initiate the inter-satellite handover process. The assumption is that the satellite chooses the new-VC establishment handover scheme, as it is not possible to augment or extend the original path.
- RR-Request: The Resource Reservation request is sent to the satellite S'_D to ask resources for the handover connection. If the resources for the handover are not available, the request is rejected.
- RR-Response: If the satellite S'_D has available resources for the handover, this message will be sent to the satellite S_D to accept the handover. In the case, that the resource does not satisfy the bandwidth requirement of the ongoing connection, the MT could be requested to re-negotiate QoS. We assume that the resource satisfies the bandwidth requirement of the MT.
- Handover Request: The satellite S_D sends the message to the gateway to indicate that the satellite S'_D will serve the MT and to require a new-VC establishment. Re-routing process is carried out by the gateway. Then the VC-assign message is sent to the satellite S'_D. After the VC assignment is completed, the VC-confirm message is replied to the gateway.
- Handover Response: After a new path has been found, the message is sent from the gateway to the satellite S_D to advertise the new path such that the handover can be further processed. It can also indicate that there are no more ATM cells coming from the gateway to the satellite S_D for this connection. At this time, cells from the gateway are sent to and queued in the satellite S'_D.
- Handover Command: The satellite S_D sends the message to the MT to indicate that the MT processes the handover to the satellite S'_D. The MT will start queuing cells in the uplink buffer. After that, the old radio uplink and down link are released.
- Handover Access: The MT accesses to the new radio link. When the access is completed, the Access Complete message is sent to the MT. After that, the MT can transmit cells over the new uplink.
- Handover Complete: This message is sent to the satellite S'_D to indicate that the satellite can send cells to the MT. After that, the message is sent to the gateway to ask for releasing the original connection.

Path-augmentation and path-extension handover protocols are shown in Fig. 5. When the satellite S_D receives Handover Start message, it sends a Handover Request message to the satellite S'_D to ask for the handover process being either the path-augmentation or the path-extension scheme. If the satellite S'_D accepts this request, i.e. resources for handover are available and the augmented or extended path is feasible, a Handover Response is sent to the satellite S_D. In the case of the path-augmentation scheme, the satellite S'_D updates its routing table after accepting the handover request. Then it is ready to queue cells, which are sent to the MT. In the path-extension scheme, the satellite S_D sends the VC-assign message to the satellite S'_D to extend the original virtual circuit after receiving the handover response message. When the satellite S_D receives the VC-confirm message, it will transmit cells to the satellite S'_D.

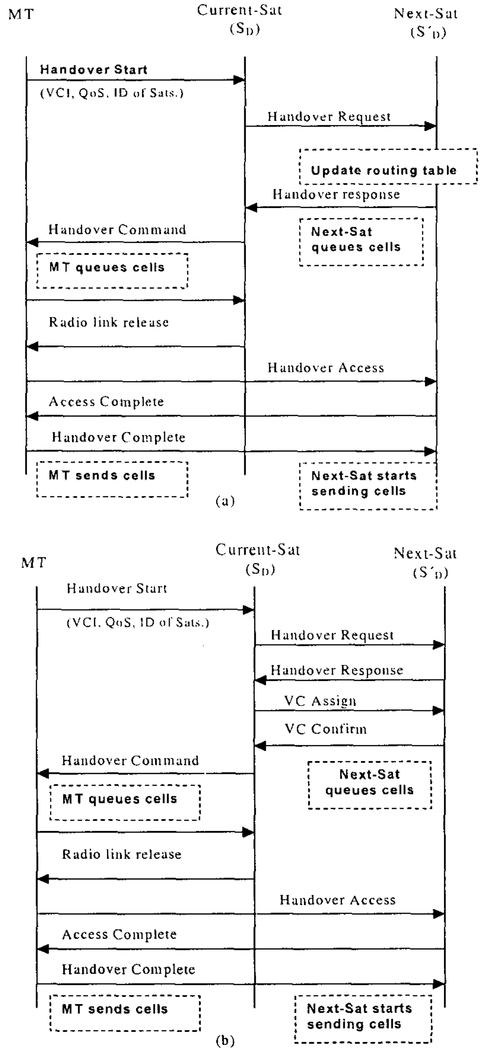


Figure 5. (a) Path-augmentation handover protocol & (b) Path-extension handover protocol

After the Handover Command message is sent to the MT, the next control sequences are similar to that of the new VC-establishment handover scheme. When the satellite S'_D receives the Handover Complete message, it has to update the new information of the connection of the MT to the gateway. That does not include here due to the clarity of the protocol presentations. Comparing with the protocol presented in Fig. 4, the signaling load and the handover process duration of both protocols in Fig. 5a and Fig. 5b are much smaller.

4.2 Simulation results

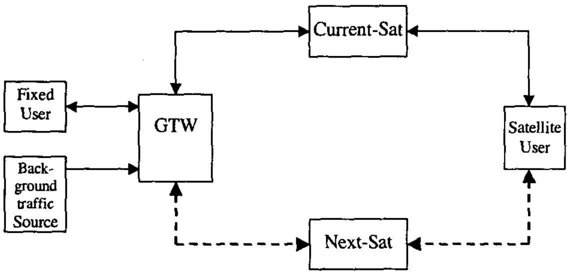


Figure 6. Simulation model

Table1: System parameters

Configuration	Uplink	Downlink
Bit rate	4 Mbit/s	4 Mbit/s
Slots per Frame	64	64
Frame duration	6.76 ms	6.76ms
Slot duration	0.11ms	0.11ms

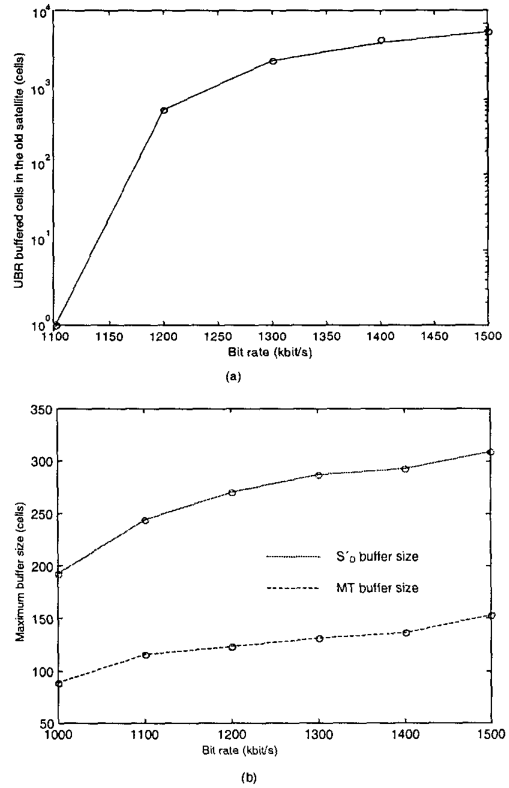
Fig. 6 shows the simulation model used with following performance metrics are evaluated: the amount of cells which are still in the buffer of the old (current) satellite S_D after handover, the maximum on-board buffer size of the new (next) satellite S'_D and the peak queue size of the MT during the handover process. The path between gateway and end satellite normally consists of a certain number of hops. The path is assumed transparent, i.e. there are not bottlenecks in the path. The gateway-to-(end) satellite delay, which includes queuing, transmission and propagation delays, is assumed to be 100 ms. The signaling flow corresponds to Fig. 4, whereby we assume that the queuing time is negligible compared with the propagation delay. The signaling delays between a MT and a satellite, between satellites, between a gateway and an end-satellite are assumed 3ms, 20 ms and 80 ms, respectively.

The handover break time is defined as the time needed for the MT to switch from the old to the new radio link. In all proposed protocols, the duration can be calculated by the equation below:

$$T_{Ho-Brk} = 4T_{sat-MT} + T_{access} + T_{release}$$

$T_{sat\text{-}MT}$: The propagation delay from the MT to an end-satellite, $T_{release}$ and T_{access} are time intervals for releasing the old radio link and accessing the new radio link, respectively.

The link capacity between the gateway and end satellite is 155 Mbit/s SDH, i.e. 149.7 Mbit/s for the payload. For user-satellite links, the size of header of transmission frames is not investigated. The assumption is that the effective downlink and uplink capacities are 4 Mbit/s. Other system parameters are showed in Table 1.



(a)

(b)

Figure 7. (a) Amount of buffered cells in the old satellite (b) Maximum buffer size for lossless handover, T_{Ho_Brk} = 100ms

Figure 7.a shows the result of an experiment in which an ongoing connection is modeled as an unspecified bit rate service (UBR), generated by Poisson traffic model. The background traffic is loaded to the downlink by a Poisson traffic with a mean bit rate of 3 Mbit/s. The ongoing connection only uses an amount of the downlink capacity, which is not used by the background traffic, i.e. the ongoing connection has low priority. The maximal amount

of UBR cells, which are still buffered in the old satellite after the old radio link is released, is calculated. The result shows the worst case that when supporting UBR services, a high amount of cells is still buffered in the old satellite after the handover.

In the second experiment, the maximum buffer size of the MT and the new satellite S'_D are evaluated with a typical value of handover break time of 100 ms. In the experiment, the system is not loaded by the background traffic. As shown in Fig. 4, to guarantee a minimum of loss during handover process, cells are buffered in both the MT and the satellite S'_D. The ongoing connection is modeled by an on-off model for a real time service [6] with the burstiness is:

$$\beta = \frac{Peak\_cell\_rate}{Mean\_cell\_rate} = 3$$

The results in Fig. 7b shows that the on-board buffer of new satellite S'_D requires a bigger size than MT 's buffer because the next satellite only transmits buffered cells after receiving the Handover Complete message while the MT starts to send cells as soon as the new radio link access has been completed, as shown in Fig. 4. The high amount of buffered cells cause large delay and delay variation, which reduce quality of real time service connections.

As seen from above results, long propagation delay would cause bad effects to QoS of ongoing connections. An important task is to design efficient solutions to reduce the amount of buffered cells in the old satellite and to reduce the delay and delay variation due to cells buffered in both the new satellite and the MT. In cellular ATM mobile networks, a forwarding method is proposed in which all buffered cells are forwarded from an old base station to a new one [7]. For LEO-satellite ATM networks, forwarding method will increase highly the complexity of on-board processing and switching. We suppose that using an extra amount of downlink resources for the handover is a more appropriate method. The solution should be that when the satellite S_D receives the Handover Start message, the cells of ongoing connection would be transmitted in the downlink by an extra resource, which is reserved for handovers. Ideally, the Handover Command message is only sent to the MT when the buffer is empty. The time duration, so-called T_{empty}, which needs to empty the buffer of the old satellite, has to be as small as possible to reduce number of buffered cells in the next satellite S'_D. To reduce end-to-end delay and delay variation after handovers, buffers on both the new satellite and the MT have to be emptied in a shortest time. Using transmission burst method, which uses extra bandwidth for emptying buffers proposed in [8], could be a most feasible solution.

5. Conclusion

In the paper, we have presented different aspects of the inter-satellite handover with QoS guarantees in LEO-satellite ATM networks. Different handover schemes have been proposed and their protocols are described in detail. The combination of the schemes should be the most efficient solution for the inter-satellite handover. Several performance metrics have been evaluated under studied traffics and a system configuration showing that the long propagation delay would cause bad effects to QoS when handover occurs. Given solutions, which aim to guarantee QoS of handover connections, have been discussed. Future works would be the investigation of the user-link extra resource reservation for handovers of connections with different QoS requirements. The optimization of the new handover paths is also the crucial topic for further studies.

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