STORE AND FORWARD FOR REAL-ENOUGH-TIME SERVICES IN SATELLITE CONSTELLATIONS

Laurent FRANCK
Ecole Nationale Supérieure des Télécommunications
10, Avenue Edouard Belin, F-31078 Toulouse CEDEX 4 - FRANCE
Tel: +33 5 62 17 83 67 Fax: +33 5 62 17 83 75
Laurent.Franck@enst.fr

Abstract The current trend favoring real-time services delivery anywhere at anytime has difficulties to cope with the dynamics of mobile networks. Furthermore, the present Internet network architecture is defeated by environments where links are error prone, intermittent, with high delay and when nodes may disappear unexpectedly. Transport services based on store and forward (such as the Delay/Disruption Tolerant Network architecture) accommodate these challenged environments. Within this framework, satellite constellations play an important role.

This contribution first presents the rationale behind store and forward transport services. Satellites and their role are then discussed with the identification of research directions to be investigated from a networking standpoint. Non-geostationary satellite constellations show promising insights for flexible yet robust store and forward transport.

Keywords: Satellite constellations, store and forward, non real-time services.

Introduction

The current trend in networking is oriented towards the provision ubiquitous, high speed, real time service. This is only possible when the environment is not too challenging (i.e. with appropriate link budget) and its characteristics do not vary in drastic ways. These conditions are unfortunately difficult to meet in mobile environments, furthermore, as far as a terrestrial networks are concerned, ubiquitous coverage requires significant infrastructure investments impacting the end-user's bill.

One possibility to lower infrastructure costs is the use of satellites either geostationary (GEO) or non-geostationary (non-GEO). GEO satellites are located 36000 km from Earth. Because of this, they suffer from long propagation delays (250 ms) and pose important design constraints on the antennas for high speed, bi-directional communications. Non-GEO satellites display propagation delays of about 20ms however, handover procedures are complex in order to comply with the real-time nature of the service.

All these pitfalls result in an increased cost for the terminals and service provision, putting at stake the viability of the business model. In this "network anywhere" race, the user is ready to trade interactivity and bandwidth for ubiquity and controlled service fees as demonstrated by the success of the short message service. Furthermore - taking the current Internet best effort traffic as an example - the lack of quality of service yields transmission delays which are acceptable in most cases, although unguaranteed.

This paradigm shift from real-time services to real-enough-time services [6] has a deep impact on the underlying communication architecture. The former puts the emphasis on optimal delivery of the message from a user standpoint. As a corollary, it is considered that the less time spent by messages in the network, the better the situation. On the other hand, networking for real-enough-time services leaves room for operator concerns: since the user requirements are less stringent, message processing may consider overall network efficiency as well. Load sharing is an example: while it impairs the end to end delay, it helps balancing the traffic load in the network. This property is crucial in wide area networks with scarce bandwidth such as a satellite network.

Real-enough-time services make also transient storage of messages acceptable since end-to-end delay constraints are weaker. For these reasons while real-time services accommodate well with fast switching architectures, so do real-enough-time services with store and forward architectures. Finally, store and forward copes smoothly with mobile environments where message storage helps facing degraded transmission conditions. As an example, the Delay/Disruption Tolerant Networking (DTN) [1] architecture relies on store and forward to provide communication facilities in challenged environments where transmission delay is high and links possibly intermittent (e.g. inter-planetary communications).

Section 1 discusses store and forward architectures for satellite networks. Section 2 details this issue for non-GEO satellites and identifies some key research directions.

1. Store and Forward with Satellites

While existing GEO satellites often only support bent pipe communication style, store and forward delivery has been implemented since a long time in small, non-GEO satellites. Amateur radio satellites (among them the famous OSCAR series [2]), work as Bulletin Board Services (BBS) in the sky. Argos and Orbcomm [5] are other examples of store and forward services based on non-GEO satellites.

Although it makes sense - as discussed later - to store messages in a non-GEO satellite, it does not in GEOs. Indeed, a GEO has a permanent link with its terrestrial control station where storage can take place. The situation is different for non-GEO: (a) satellites may not be in permanent contact with earth stations (b) satellites can take the opportunity of their trajectory to "deliver at the door" messages. In addition, non-GEO satellites offer the following advantages: (a) enhanced coverage at higher latitudes, (b) smaller terminals (in size and consumption) and (c) improved robustness against transmission obstacles (thanks to the satellite motion). On the other hand, a satellite footprint is smaller and therefore many satellites are required for a global coverage.

Service categories supported by store and forward satellites are Earth observation (sensor data collection, sensor re-tasking), personal communication and entertainment (e-mail, short message) and selective data broadcasting (web pushing, infocasting).

As an example, the COSPAS/SARSAT programme [3] is designed to track emergency beacons. This system is based on non-GEO and GEO satellites. Both types of satellites are complementary, the former providing accurate albeit delayed localization, the latter offering instantaneous alert (if the beacon is not masked) without localization. With the current system, a beacon location is obtained within one hour. This is the average time for a non-GEO to capture and transmit the message to the Message Control Centre (MCC) via one of the 43 Local Users Terminals (LUT). Shorter delays would require an increased number of non-GEO satellites and/or to equip the constellation with inter satellite communication facilities.

The following section discusses issues raised by a store and forward architecture in a constellation of non-GEO satellites. Two scenarios are considered: a constellation with and without Inter-Satellite Links (ISLs). In both cases, the objective is to make inter satellite communication feasible either indirectly (via earth station) or directly. Store and forward services were often studied in the frame of non-GEO satellites however, to the author's knowledge, the satellites forming the constellation are only considered as individual entities. Taking into account the earth stations as relaying elements among satellites or the possibilities offered by ISLs was seldom envisaged. On the other hand, the use of ISLs has been widely studied for real-time services, however as we will try to demonstrate, real time and real enough time services do not display the same requirements.

2. Store and Forward networking in non-GEO Satellites

Non-GEO satellites sweep the Earth in a periodic manner at a lower altitude than the geostationary orbit. For these reasons, the coverage of a satellite is smaller than a single GEO footprint. Constellations of such satellites help to alleviate this problem by providing multiple continuous footprints. Each satellite of a constellation may be equipped with ISLs in order to avoid multi-hops through earth stations when source and destination terminals span multiple footprints. While it reduces the number of required earth stations, it also increases the payload complexity.

From a networking standpoint, constellations with and without ISLs have to address the same basic issues: routing of messages from the source to the destination terminals, preventing and curing congestion in the satellite network.

Routing

Routing is subdivided in two categories: up/down link routing and space segment routing. Up/down link routing consists in selecting the source and destination satellites. Space segment routing consists in selecting the satellites and links that will make the path between the source and destination satellites.

Up/down link routing. The up/down link routing strategy between the terrestrial and space segments must be efficiently devised, especially with mobile terminals. Uplinking to a satellite must take into account the course of the user messages to the destination. For example, selecting a satellite which motion is working against the traffic course might impact routing efficiency in the space segment depending on the constellation geometry. This concern raises the issue of whether up/down link routing should be integrated with space segment routing or not (i.e. considered as a single path finding problem from the source terminal to the destination terminal). On the one hand, integrated routing yields paths tending to be more optimal than considering up/down link and space segment routing as two separate processes. On the other hand, it implies that terminals and satellites need remote network state information, hence the necessity to establish costly signaling schemes. This issue has been addressed in [7].

Space segment routing. Depending on whether or not the constellation is equipped with ISLs, different approaches are possible. In both cases, the non-real time nature of the traffic raises an interesting issue. While the usual motto is store and forward, a more appropriate question is store *or* forward. Indeed, a satellite may store a message, making profit of its track to deliver it more efficiently to another satellite or earth station.

If the constellation is not equipped with ISLs, the earth stations may play an important role in networking as relay from one satellite to the other as well as temporary overflow buffer in case of congestion. The cost of relaying/storing in the earth station must be balanced with the cost of storing in the satellite and taking into account the course of the satellite.

In the case of an ISL network, the situation is even richer: in addition to earth station acting as relay buffers, ISLs provide a quick way to transfer messages from on satellite to another. ISL routing has been extensively discussed in the literature [9, 8, 10] however, these contributions do not take into account the non real-time nature of the traffic and aim mostly at optimizing end-to-end delay.

Congestion control

Congestion control is closely linked to routing decisions, the latter participating actively in preventing congestion. From a curative standpoint, congestion control beneficiates from a new dimension thanks to the non real-time nature of the traffic. Adjacent satellites and earth stations may help to quickly alleviate the load of a congested satellite yet with the possibility to smoothly integrate long term routing policies in the congestion treatment. This way of operating has seldom been investigated in the literature.

3. Conclusion

Non real-time services have been disregarded these last years because of the urge to deliver multimedia contents anywhere at anytime. However, mobile environments make real-time services difficult to support for the mass market. This paper describes the various contributions of non-geostationary satellite constellations in the delivery of non-real time services. One of the emerging application frameworks is the Delay Tolerant Networks architecture (DTN).

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