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Network coding and satellites
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Abstract

This memo presents the current deployment of network coding in some satellite telecommunications systems along with a discussion on the multiple opportunities to introduce these techniques at a wider scale.

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1. Introduction

Guaranteeing both physical layer robustness and efficient usage of the radio resource has been in the core design of SATellite COMMunication (SATCOM) systems. The trade-off often resided in how much redundancy a system had to add to cope from link impairments, without reducing the good-put when the channel quality is high. Generally speaking, enough redundancy is added so as to guarantee a Quasi-Error Free transmission; however, there are cases where the physical layer could hardly recover the transmission losses (e.g. with a mobile user) and layer 2 (or above) re-transmissions induce an at least 500 ms delay with a geostationary satellite. Further exploiting network coding schemes at higher OSI-layers is an opportunity for releasing constraints on the physical layer and improve the performance of SATCOM systems when the physical layer is challenged. We have noticed an active research activity on how network coding and SATCOM in the past. That being said, not much has actually made it to industrial developments. In this context, this memo aims at:

- o summing up the current deployment of network coding schemes over LEO and GEO satellite systems;

- o identifying opportunities for further usage of network coding in these systems.

1.1. Glossary

The glossary of this memo is related to the network coding taxonomy document [I-D.irtf-nwcrp-network-coding-taxonomy].

The glossary is extended as follows:

- o BBFRAME: Base-Band FRAME - satellite communication layer 2 encapsulation work as follows: (1) each layer 3 packet is encapsulated with a Generic Stream Encapsulation (GSE) mechanism, (2) GSE packets are gathered to create BBFRAMEs, (3) BBFRAMEs contain information related to how they have to be modulated (4) BBFRAMEs are forwarded to the physical layer;
- o CPE: Customer Premise Equipment;
- o DTN: Delay/Disruption Tolerant Network;
- o EPC: Evolved Packet Core;
- o ETSI: European Telecommunications Standards Institute;
- o PEP: Performance Enhanced Proxy - a typical PEP for satellite communications include compression, caching and TCP acceleration;
- o PLFRAME: Physical Layer FRAME - modulated version of a BBFRAME with additional information (e.g. related to synchronization);
- o SATCOM: generic term related to all kind of SATellite COMMunications systems;
- o UMTRAN: Universal Mobile Terrestrial Radio Access Network;
- o QoS: Quality-of-Service;
- o QoE: Quality-of-Experience;
- o VNF: Virtualized Network Function.

1.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. A note on satellite topology

The objective of this section is to provide both a generic description of the components composing a generic satellite system and their interaction. It provides a high level description of a multi-gateway satellites network. There exist multiple SATCOM systems, such as those dedicated to broadcasting TV or to IoT applications: depending on the purpose of the SATCOM system, ground segments are specific. This memo lays on SATCOM systems dedicated to Internet access that follows the DVB-S2/RCS2 standards.

In this context, Figure 1 shows an example of a multi-gateway satellite system. More details on a generic SATCOM ground segment architecture for a bi-directional Internet access can be found in [SAT2017]. We propose a multi-gateway system since some of the use-cases described in this document require multiple gateways. In a multi-gateway system, some elements may be centralized and/or gathered: the relevance of one approach compared to another depends on the deployment scenario. More information on these trade-off discussions can be found in [SAT2017].

It is worth noting that some functional blocks aggregate the traffic coming from multiple users. Even if network coding schemes could be applied to any individual traffic, it could also work on a aggregate.

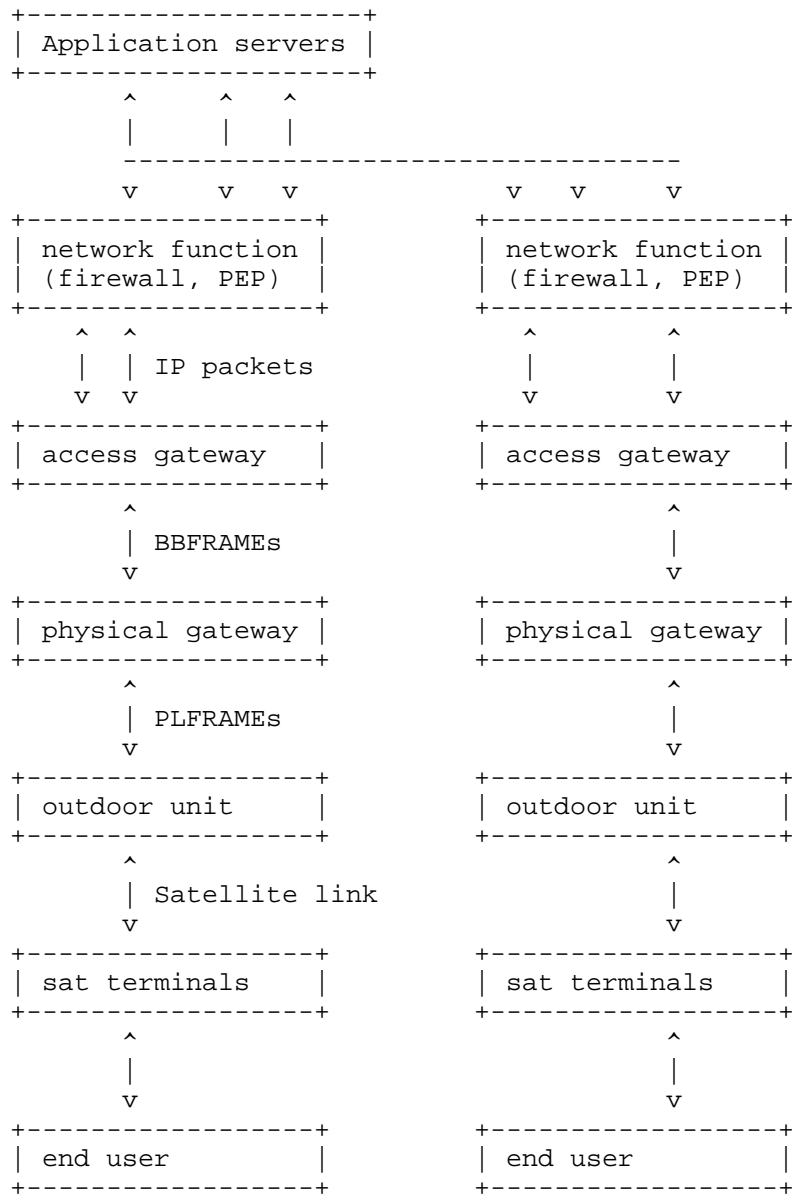


Figure 1: Data plane functions in a generic satellite multi-gateway system

3. Status of network coding in actually deployed satellite systems

Figure 2 presents the status of the network coding deployment in satellite systems. The information is based on the taxonomy document [I-D.irtf-nwcr-g-network-coding-taxonomy] and the notations are the following: End-to-End Coding (E2E), Network Coding (NC), Intra-Flow Coding (IntraF), Inter-Flow Coding (InterF), Single-Path Coding (SP) and Multi-Path Coding (MP).

X1 embodies the source coding that could be used at application level for instance: for video streaming on a broadband access. X2 embodies the physical layer, applied to the PLFRAME, to optimize the satellite capacity usage. Furthermore, at the physical layer and when random accesses are exploited, FEC mechanisms are exploited.

| | Upper Appl. | Middle ware | Communication layers | |
|--------|------------------|-------------------|-------------------------|--------------|
| | Source coding | Network AL-FEC | Packetization UDP/IP | PHY layer |
| E2E | X1 | | | |
| NC | | | | |
| IntraF | X1 | | | |
| InterF | | | | X2 |
| SP | X1 | | | X2 |
| MP | | | | |

Figure 2: Network coding in current satellite systems

4. Details on the use cases

This section details use-cases where network coding schemes could improve the overall performance of a SATCOM system (e.g. considering a more efficient usage of the satellite resource, delivery delay, delivery ratio).

It is worth noting that these use-cases focus more on the middleware (e.g. aggregation nodes) and packetization UDP/IP of Figure 2. Indeed, there are already lots of recovery mechanisms at the physical and access layers in currently deployed systems while E2E source coding are done at the application level. In a multi-gateway SATCOM Internet access, the specific opportunities are more relevant in specific SATCOM components such as the "network function" block or the "access gateway" of Figure 1.

4.1. Two way relay channel mode

This use-case considers a two-way communication between end users, through a satellite link. We propose an illustration of this scenario in Figure 3.

Satellite terminal A (resp. B) transmits a flow A (resp. B) to a server hosting NC capabilities, which forward a combination of the two flows to both terminals. This results in non-negligible bandwidth saving and has been demonstrated at ASMS 2010 in Cagliari [ASMS2010]. Moreover, with On-Board Processing satellite payloads, the network coding operations could be done at the satellite level, thus reducing the end-to-end delay of the communication.

-X>- : traffic from satellite terminal X to the server
 ={X+Y= : traffic from X and Y combined transmitted from
 the server to terminals X and Y

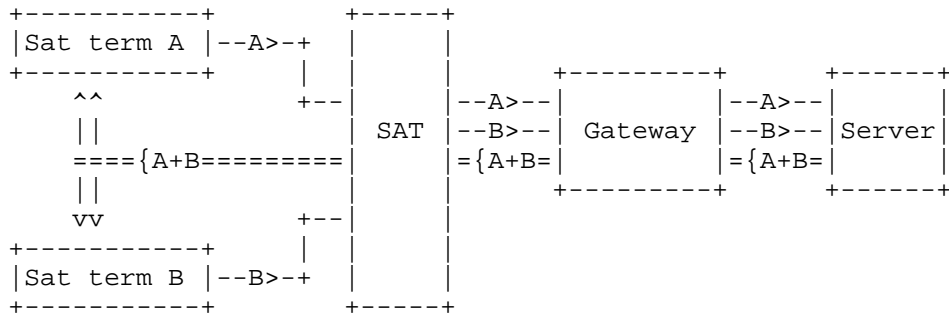


Figure 3: Network architecture for two way relay channel with NC

4.2. Reliable multicast

This use-case considers adding redundancy to a multicast flow depending on what has been received by different end-users, resulting in non-negligible scarce resource saving. We propose an illustration for this scenario in Figure 4.

A multicast flow (M) is forward to both satellite terminals A and B. On the uplink, terminal A (resp. B) does not acknowledge the packet N_i by sending a L_i signal (resp. N_j , L_j) and either the access gateway or the multicast server includes the missing packets in the multicast flow so that the information transfer is reliable. This could be achieved by using NACK-Oriented Reliable Multicast (NORM) [RFC5740]. However, NORM does not consider other network coding schemes such as sliding window encoding described in [I-D.irtf-nwcrg-network-coding-taxonomy].

-Li>- : packet indicated the loss of packet i of a multicast flow
 = {M== : multicast flow including the missing packets

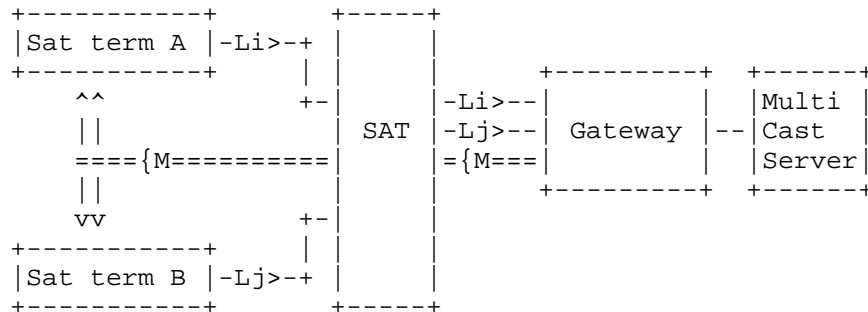


Figure 4: Network architecture for a reliable multicast with NC

4.3. Hybrid access

This use-case considers the use of multiple path management with network coding at the transport level to increase the reliability and/or the total bandwidth (using multiple path does not guarantee an improvement of both the reliability and the total bandwidth). We propose an illustration for this scenario in Figure 5. This use-case is inspired from the Broadband Access via Integrated Terrestrial Satellite Systems (BATS) project and has been published as an ETSI Technical Report [ETSITR2017]. It is worth nothing that this kind of architecture is also discussed in the MPTCP working group [I-D.boucadair-mptcp-dhc].

To cope from packet loss (due to either end-user movements or physical layer impairments), network coding could be introduced in both the CPE and at the concentrator.

->- : bidirectional link

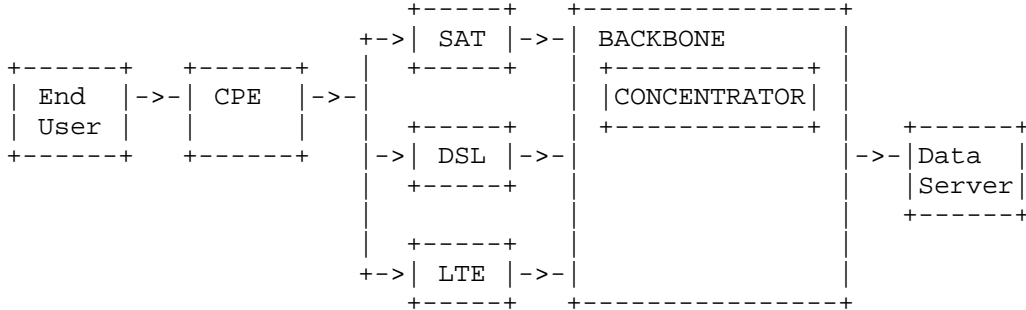


Figure 5: Network architecture for an hybrid access using NC

4.4. Dealing with varying capacity

This use-case considers the usage of network coding to overcome cases where the wireless link characteristics quickly change overtime and where the physical layer codes could not be made robust in time. This is particularly relevant when end users are moving and the channel shows important variations [IEEEVT2001].

The architecture is recalled in Figure 6. The network coding schemes could be applied at the access gateway or the network function levels to increase the reliability of the transmission. This use-case is mostly relevant for when mobile users are considered or when the chosen band induce a required physical layer coding that may change over time (Q/V bands, Ka band, etc.). Depending on the use-case (e.g. very high frequency bands, mobile users) or depending on the deployment use-cases (e.g. performance of the network between each individual block), the relevance of adding network coding is different. Then, depending on the OSI level at which network coding is applied, the impact on the satellite terminal is different: network coding may be applied on IP packets or on layer-2 proprietary format packets.

->- : bidirectional link

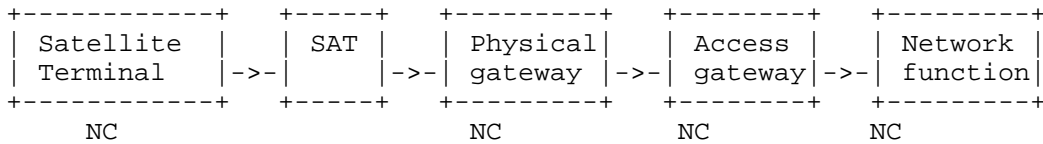


Figure 6: Network architecture for dealing with varying link characteristics with NC

4.5. Improving the gateway handovers

This use-case considers the recovery of packets that may be lost during gateway handovers. Whether this is for off-loading one given equipment or because the transmission quality is not the same on each gateway, changing the transmission gateway may be relevant. However, if gateways are not properly synchronized, this may result in packet loss. During these critical phases, network coding can be added to improve the reliability of the transmission and propose a seamless gateway handover. In this case, the network coding could be applied at either the access gateway or the network function block. The entity responsible for taking the decision to change the communication gateway and changing the routes is the control plane manager; this entity exploits a management interface.

An example architecture for this use-case is showed in Figure 7. It is worth noting that depending on the ground architecture [I-D.chin-nfvrg-cloud-5g-core-structure-yang] [SAT2017], some equipment might be communalised.

->- : bidirectional link
! : management interface

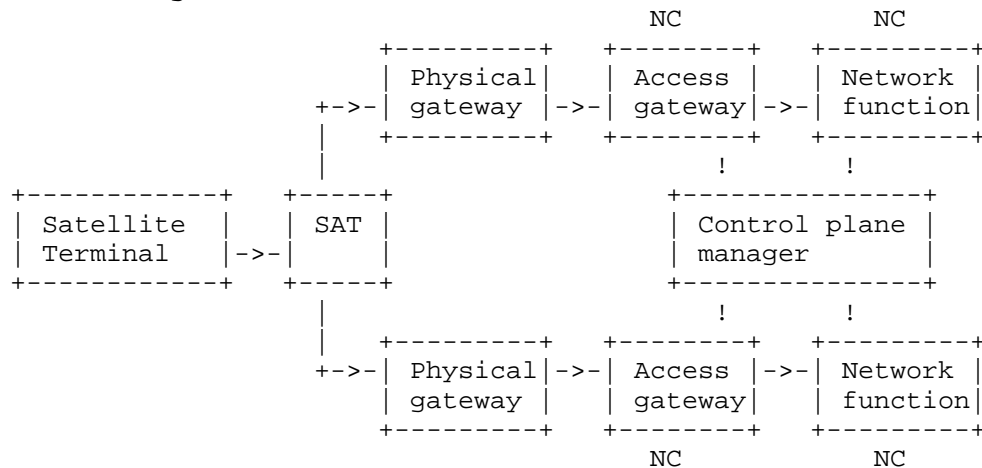


Figure 7: Network architecture for dealing with gateway handover schemes with NC

4.6. Delay/Disruption Tolerant Networks

Establishing communications from terrestrial gateways to aerospace components is a challenge due to the distances involved. As a matter of fact, reliable end-to-end (E2E) communications over such links must cope with long delay and frequent link disruptions. Delay/

Disruption Tolerant Networking [RFC4838] is a solution to enable reliable internetworking space communications where both standard ad-hoc routing and E2E Internet protocols cannot be used. DTN can also be seen as an alternative solution to cope with satellite communications usually managed by PEP. Therefore, the transport of data over such networks requires the use of replication, erasure codes and multipath protocol schemes [WANG05] [ZHANG06] to improve the bundle delivery ratio and/or delivery delay. For instance, transport protocols such as LTP [RFC5326] for long delay links with connectivity disruptions, use Automatic Repeat-reQuest (ARQ) and unequal error protection to reduce the amount of non-mandatory re-transmissions. The work in [TOURNOUX10] proposed upon LTP a robust streaming method based on an on-the-fly coding scheme, where encoding and decoding procedures are done at the source and destination nodes, respectively. However, each link path loss rate may have various order of magnitude and re-encoding at an intermediate node to adapt the redundancy can be mandatory to prevent transmission wasting. This idea has been put forward in [I-D.zinky-dtnrg-random-binary-fec-scheme] and [I-D.zinky-dtnrg-erasure-coding-extension], where the authors proposed an encoding process at intermediate DTN nodes to explore the possibilities of Forward Error Correction (FEC) schemes inside the bundle protocol [RFC5050]. Another proposal is the use of erasure coding inside the CCSDS (Consultative Committee for Space Data Systems) architecture [COLA11]. The objective is to extend the CCSDS File Delivery Protocol (CFDP) [CCSDS-FDP] with erasure coding capabilities where a Low Density Parity Check (LDPC) [RFC6816] code with a large block size is chosen. Recently, on-the-fly erasure coding schemes [LACAN08] [SUNDARARAJAN08] [TOURNOUX11] have shown their benefits in terms of recovery capability and configuration complexity compared to traditional FEC schemes. Using a feedback path when available, on-the-fly schemes can be used to enable E2E reliable communication over DTN with adaptive re-encoding as proposed in [THAI15].

5. Discussion on the deployability

This section discusses the deployability of the use-cases detailed in Section 4.

SATCOM systems typically feature Performance Enhancement Proxy RFC 3135 [RFC3135] which could be relevant to host network coding mechanisms and thus support the use-cases that have been discussed in Section 4. In particular the discussion on how network coding can be integrated inside a PEP with QoS scheduler has been proposed in RFC 5865 [RFC5865].

Related to the foreseen virtualized network infrastructure, the network coding schemes could be proposed as VNF and their deployability enhanced. The architecture for the next generation of SATCOM ground segments would rely on a virtualized environment. This trend can also be seen, making the discussions on the deployability of network coding in SATCOM extendable to other deployment scenarios [I-D.chin-nfvrg-cloud-5g-core-structure-yang]. As one example, the network coding VNF functions deployment in a virtualized environment is presented in [I-D.vazquez-nfvrg-netcod-function-virtualization].

6. Conclusion

This document presents the current deployment of network coding in some satellite telecommunications systems along with a discussion on the multiple opportunities to introduce these techniques at a wider scale.

Even if this document focuses on satellite systems, it is worth pointing out that the some scenarios proposed may be relevant to other wireless telecommunication systems. As one example, the generic architecture proposed in Figure 1 may be mapped to cellular networks as follows: the 'network function' block gather some of the functions of the Evolved Packet Core subsystem, while the 'access gateway' and 'physical gateway' blocks gather the same type of functions as the Universal Mobile Terrestrial Radio Access Network. This mapping extends the opportunities identified in this draft since they may be also relevant for cellular networks.

7. Acknowledgements

Many thanks to Tomaso de Cola, Vincent Roca and Marie-Jose Montpetit.

8. Contributors

Tomaso de Cola, Marie-Jose Montpetit.

9. IANA Considerations

This memo includes no request to IANA.

10. Security Considerations

This document, by itself, presents no new privacy nor security issues.

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