Internet Engineering Task Force
Internet-Draft
Intended status: Informational
Expires: July 7, 2019

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Jan 3, 2019

Network coding and satellites
draft-irtf-nwcrg-network-coding-satellites-04

Abstract

This memo details a multi-gateway satellite system to identify multiple opportunities on how coding techniques could be deployed 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 adds to cope from link impairments, without reducing the good-put when the channel quality is high. There is usually enough redundancy to guarantee a Quasi-Error Free transmission. However, physical layer reliability mechanisms may not recover transmission losses (e.g. with a mobile user) and layer 2 (or above) re-transmissions induce 500 ms one-way delay with a geostationary satellite. Further exploiting coding schemes at higher OSI-layers is an opportunity for releasing constraints on the physical layer in such cases and improving the performance of SATCOM systems.

We have noticed an active research activity on coding and SATCOM in the past. That being said, not much has actually made it to industrial developments. In this context, this document aims at identifying opportunities for further usage of coding in these systems.

This document follows the taxonomy of coding techniques for efficient network communications [RFC8406].

1.1. Glossary

The glossary of this memo extends the glossary of the taxonomy document [RFC8406] as follows:

- ACM : Adaptative Coding and Modulation;
- 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;
- CPE: Customer Premise Equipment;
- COM: COMmunication;
- DSL: Digital Subscriber Line;
- DTN: Delay/Disruption Tolerant Network;
- ETSI: European Telecommunications Standards Institute;
- FEC: Forward Erasure Correction;
- FLUTE: File Delivery over Unidirectional Transport;
- IoT: Internet of Things;
- LTE: Long Term Evolution;
- NFV: Network Function Virtualization;
- NORM: NACK-Oriented Reliable Multicast;
- PEP: Performance Enhanced Proxy [RFC3135] - a typical PEP for satellite communications include compression, caching and TCP acceleration;
- PLFRAME: Physical Layer FRAME - modulated version of a BBFRAME with additional information (e.g. related to synchronization);
- QEF: Quasi-Error-Free;
- QoE: Quality-of-Experience;
- QoS: Quality-of-Service;

- o SAT: SATellite;

- o SATCOM: generic term related to all kind of SATellite COMmunication systems;

- o VNF: Virtual Network Function.

2. A note on satellite topology

This section describes the components in satellite system that lays on SATCOM systems dedicated to broadband Internet access that follows the DVB standards. A high-level description of a multi-gateway satellites network is provided. There are 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. In this context, the increase of the available capacity that is carried out to end users and reliability requirements lead to multiple gateways for one unique satellite platform.

In this context, Figure 1 shows an example of a multi-gateway satellite system. 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 discussions and a generic SATCOM ground segment architecture for a bi-directional Internet access can be found in [SAT2017].

Some functional blocks aggregate the traffic of multiple users. Coding schemes could be applied on both single and aggregated traffic.

```
   +---------------------+
   | application servers |
   +---------------------+
          ^     ^
          | ... |
          -----------------------------------
          v     v   v             v   v     v
   +------------------+         +------------------+
   | network function |         | network function |
   | (firewall, PEP)  |         | (firewall, PEP)  |
   +------------------+         +------------------+
       ^     ^                        ^        ^
       | ... | IP packets             |  ...   |
       v     v                        v        v
   +------------------+         +------------------+
   | access gateway   |         | access gateway   |
   +------------------+         +------------------+
          ^                                 ^
          | BBFRAME                         |
          v                                 v
   +------------------+         +------------------+
   | physical gateway |         | physical gateway |
   +------------------+         +------------------+
          ^                                 ^
          | PLFRAME                         |
          v                                 v
   +------------------+         +------------------+
   | outdoor unit     |         | outdoor unit     |
   +------------------+         +------------------+
          ^                                 ^
          | satellite link                  |
          v                                 v
   +------------------+         +------------------+
   | sat terminals    |         | sat terminals    |
   +------------------+         +------------------+
          ^     ^                  ^     ^
          | ... |                  | ... |
          v     v                  v     v
   +------------------+         +------------------+
   | end user         |         | end user         |
   +------------------+         +------------------+
```

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

3. Actual deployment of reliability schemes in satellite systems

The notations used in this section are based on the taxonomy document [RFC8406]: End-to-End Coding (E2E), Network Coding (NC), Intra-Flow Coding (IntraF), Inter-Flow Coding (InterF), Single-Path Coding (SPC) and Multi-Path Coding (MPC). This document refers to coding as both End-to-End Coding and Network Coding, to cover cases where where recoding operation at intermediate nodes are or not. From the UDP/IP packetization to the channel coding, link layer coding is required so that the physical-layer knows what coding scheme to use. Following the taxonomy document [RFC8406], channel and link codings are gathered in the PHY layer coding and are out of the scope of this document.

Figure 2 presents the status of the reliability schemes deployment in satellite systems.

- o X1 embodies the source coding that could be used at application level for instance within QUIC or other video streaming applications. This is not specific to SATCOM systems since such deployment can be relevant for broadband Internet access discussions.

- o X2 embodies the physical-layer, applied to the PLFRAME, to optimize the satellite capacity usage. At the physical layer, FEC mechanisms can be exploited.

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

Figure 2: Reliability schemes in current satellite systems

Reliability is an inherent part of the physical-layer and usually achieved by using coding techniques. Based on public information, coding does not seem to be widely used at higher layers.

4. Details on the use cases

This section details use-cases where 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 mostly focus on the middleware and packetization UDP/IP of Figure 2. There are already lots of recovery mechanisms at the physical-layer in currently deployed systems while E2E source coding is done at the application level. In a multi-gateway SATCOM Internet access, the deployment 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. Figure 3 proposes an illustration of this scenario.

Satellite terminal A sends a flow A and satellite terminal B sends a flow B to a NC server. The NC server sends a combination of both terminal flows. This results in non-negligible capacity savings and has been demonstrated [ASMS2010]. Moreover, with On-Board Processing satellite payloads, the coding operations could be done at the satellite level.

```
-X}-   : traffic from satellite terminal X to the server
={X+Y= : traffic from X and Y combined sent from
            the server to terminals X and Y

+-----------+        +-----+
|Sat term A |--A}-+  |     |
+-----------+     |  |     |      +---------+      +------+
    ^^            +--|     |--A}--|         |--A}--|      |
    ||               | SAT |--B}--| Gateway |--B}--|Server|
    ===={A+B=========|     |={A+B=|         |={A+B=|      |
    ||               |     |      +---------+      +------+
    vv            +--|     |
+-----------+     |  |     |
|Sat term B |--B}-+  |     |
+-----------+        +-----+
```

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

4.2. Reliable multicast

Using multicast servers is a way to better exploit the satellite broadcast capabilities. This approach is proposed in the SHINE ESA project [I-D.vazquez-nfvrg-netcod-function-virtualization] [SHINE]. 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 forwarded to both satellite terminals A and B. However packet Ni (resp. Nj) get lost at terminal A (resp. B), and terminal A (resp. B) returns a negative acknowledgment Li (resp. Lj), indicating that the packet is missing. Then either the access gateway or the multicast server includes a repair packet (rather than the individual Ni and Nj packets) in the multicast flow to let both terminals recover from losses. This could be achieved by using NACK-Oriented Reliable Multicast (NORM) [RFC5740] in situations where a feedback link is available, or File Delivery over Unidirectional Transport (FLUTE) [RFC6726] otherwise. Note that both NORM and FLUTE are limited to block coding, none of them supporting sliding window encoding schemes [RFC8406].

```
-Li}- : packet indicating the loss of packet i of a multicast flow M
={M== : multicast flow including the missing packets

+-----------+       +-----+
|Sat term A |-Li}-+ |     |
+-----------+     | |     |      +---------+  +------+
    ^^            +-|     |-Li}--|         |  |Multi |
    ||              | SAT |-Lj}--| Gateway |--|Cast  |
    ===={M==========|     |={M===|         |  |Server|
    ||              |     |      +---------+  +------+
    vv            +-|     |
+-----------+     | |     |
|Sat term B |-Lj}-+ |     |
+-----------+       +-----+
```

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 coding at the transport level to increase the reliability and/or the total capacity (using multiple path does not guarantee an improvement of both the reliability and the total capacity). 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]. This kind of architecture is also discussed in the TCPM working group [I-D.ietf-tcpm-converters].

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

```
 -{}- : bidirectional link

                            +-----+    +-----------------+
                       +-{}-| SAT |-{}-| BACKBONE        |
 +-------+    +-------+    |    +-----+    | +-------------+ |
 | End  |-{}-| CPE  |-{}-|               | |CONCENTRATOR| |
 | User |    |      |    |    +-----+    | +-------------+ |    +-------+
 +-------+    +-------+    |-{}-| DSL |-{}-|                 |-{}-|Data  |
                       |    +-----+    |                 |    |Server|
                       |               |                 |    +-------+
                       |    +-----+    |                 |
                       +-{}-| LTE |-{}-|                 |
                            +-----+    +-----------------+
```

Figure 5: Network architecture for an hybrid access using NC

4.4. Dealing with varying capacity

This use-case considers the usage of coding to cope with cases where channel condition can change in less than a second and where the physical-layer codes could not guarantee a Quasi-Error-Free (QEF) transmission.

The architecture is recalled in Figure 6. In these cases, Adaptative Coding and Modulation (ACM) may not adapt the modulation and coding accordingly and remaining errors could be recovered with higher layers redundancy packets. The coding schemes could be applied at the access gateway or the network function block levels to increase the reliability of the transmission. Coding may be applied on IP packets or on layer-2 proprietary format packets.

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 coding is different.

```
-{}- : bidirectional link

+---------+    +---+    +--------+    +-------+    +--------+
|Satellite|    |SAT|    |Physical|    |Access |    |Network |
|Terminal |-{}-|   |-{}-|Gateway |-{}-|Gateway|-{}-|Function|
+---------+    +---+    +--------+    +-------+    +--------+
     NC                      NC           NC          NC
```

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, coding can be added to improve the reliability of the transmission and allow a seamless gateway handover. Coding could be applied at either the access gateway or the network function block. The control plane manager is in charge of taking the decision to change the communication gateway and the consequent routes.

Figure 7 illustrates this use-case. Depending on the ground architecture [I-D.chin-nfvrg-cloud-5g-core-structure-yang] [SAT2017], some equipment might be communalised.

```
   -{}- : bidirectional link
   !    : management interface
                                          NC            NC
                         +--------+    +-------+    +--------+
                         |Physical|    |Access |    |Network |
                    +-{}-|gateway |-{}-|gateway|-{}-|function|
                    |    +--------+    +-------+    +--------+
                    |                        !       !
   +---------+    +---+             +---------------+
   |Satellite|    |SAT|             | Control plane |
   |Terminal |-{}-|   |             | manager       |
   +---------+    +---+             +---------------+
                    |                        !       !
                    |    +--------+    +-------+    +--------+
                    +-{}-|Physical|-{}-|Access |-{}-|Network |
                         |gateway |    |gateway|    |function|
                         +--------+    +-------+    +--------+
                                          NC            NC
```

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

5. Research challenges

5.1. Towards an increased deployability in SATCOM systems

SATCOM systems typically feature Performance Enhancement Proxy (PEP) RFC 3135 [RFC3135]. PEP usually split TCP end-to-end connections and forward TCP packets to the satellite baseband gateway that deals with layer-2 and layer-1 encapsulations. PEP could host coding mechanisms and thus support the use-cases that have been discussed in this document.

Deploying coding schemes at the TCP level in these equipment could be relevant and independent from the specific characteristics of a SATCOM link. However, there is a research issue in the recurrent trade-off in SATCOM systems: how much overhead from redundant reliability packets can be introduced to guarantee a better end-user QoE while optimizing capacity usage ?

5.2. Interaction with virtualization

Related to the foreseen virtualized network infrastructure, coding schemes could be easily deployed as VNF. Next generation of SATCOM ground segments could rely on a virtualized environment. This trend can also be seen in cellular networks, making these discussions extendable to other deployment scenarios [I-D.chin-nfvrg-cloud-5g-core-structure-yang]. As one example, the

coding VNF functions deployment in a virtualized environment is presented in [I-D.vazquez-nfvrg-netcod-function-virtualization].

A research challenge would be the optimization of the NFV service function chaining, considering a virtualized infrastructure and other SATCOM specific functions, to guarantee an efficient radio usage and easy-to-deploy SATCOM services.

5.3. Delay/Disruption Tolerant Networks

In the context of the deep-space communications, establishing communications from terrestrial gateways to satellite platforms can be a challenge. 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. Moreover, DTN can also be seen as an alternative solution to transfer the data between a central PEP and a remote PEP.

Coding enables E2E reliable communication over DTN with adaptive re-encoding, as proposed in [THAI15]. In this case, the use-cases proposed in Section 4.4 would legitimate the usage of coding within the DTN stack to improve the channel utilization and the E2E transmission delay. In this context, the use of erasure coding inside a Consultative Committee for Space Data Systems (CCSDS) architecture has been specified in [CCSDS-131.5-O-1]. A research challenge would be on how such coding can be integrated in the IETF DTN stack.

6. Conclusion

This document discuses some opportunities to introduce these techniques at a wider scale in satellite telecommunications systems.

Even though 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, Lloyd Wood and Marie-Jose Montpetit for their help in writing this document.

8. IANA Considerations

This memo includes no request to IANA.

9. Security Considerations

Security considerations are inherent to any access network. SATCOM systems introduce standard security mechanisms. On the specific scenario of NC in SATCOM systems, there are no specific security considerations.

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