Abstract

This document is the product of the Coding for Efficient Network Communications Research Group (NWCRG). This document follows the taxonomy document [RFC8406] and considers coding as a linear combination of packets that operate in and above the network layer. In this context, this memo details a multi-gateway satellite system to identify use-cases where network coding is relevant. As example, network coding operating in and above the network layer can be exploited to cope with residual losses or provide reliable multicast services. The objective is to contribute to a larger deployment of such techniques in SATCOM systems. This memo also identifies open research issues related to the deployment of network coding in SATCOM systems, such as the interaction between congestion control and network coding techniques.

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Exploiting network coding techniques at application or transport layers is an opportunity for improving the end-to-end performance of SATCOM systems. Physical and link layers coding protection is usually sufficient to guarantee Quasi-Error Free, with a negligible
delay compared to the propagation time (e.g., with a GEO sat). When the physical and link layers coding fails, retransmissions add significant delays. Hence the use of network coding in upper layers can improve the quality of experience of end users.

We notice an active research activity on network coding techniques above the network layer and SATCOM. 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 network coding in these systems.

The notations used in this document are based on the taxonomy document [RFC8406]:

- Channel and link codings are gathered in the PHY layer coding and are out of the scope of this document.
- FEC (also called Application-Level FEC) operates in and above the network layer.
- This document considers coding (or coding techniques or coding schemes) as a linear combination and not as a content coding (e.g., to compress a video flow).

2. A note on satellite topology

There are multiple SATCOM systems, such as those dedicated to broadcasting TV or to IoT applications: depending on the purpose of the SATCOM system, the ground segments are different. This section focuses on a satellite system that follows the ETSI DVB standards to provide broadband Internet access. The capacity that is carried out by one satellite may be higher than the capacity that one single gateway can carry out: there are usually multiple gateways for one unique satellite platform.

In this context, Figure 1 shows an example of a multi-gateway satellite system. More information on a generic SATCOM ground segment architecture for bidirectional Internet access can be found in [SAT2017].
Figure 1: Data plane functions in a generic satellite multi-gateway system. More details can be found in DVB standard documents.
3. Use-cases for improving the SATCOM system performance with network coding

This section details use-cases where network coding techniques could improve SATCOM systems.

3.1. Two-way relay channel mode

This use-case considers a two-way communication between end users, through a satellite link. Figure 2 proposes an illustration of this scenario.

Satellite terminal A sends a flow A and satellite terminal B sends a flow B to a coding server. The coding server sends a combination of both terminal flows. This results in non-negligible capacity savings and has been demonstrated [ASMS2010]. In the proposed example, a dedicated coding server is introduced (note that its location could be different for another deployment use-case). The network coding operations could also be done at the satellite level, although this would require lots of computational resource on-board and may not be relevant with today’s satellites.

- $X)$- : 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}--|Coding|
||               |     |      +---------+      +------+
=={(A+B=---------|     |={A+B=|         |={A+B=|      |
=={(A+B=        |     |      +---------+      +------+
vv            +--|     |
+-----------+     |  |     |
|Sat term B |--B}-+  |     |
+-----------+        +-----+
```

Figure 2: Network architecture for two way relay channel with NC

3.2. 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-nfvg-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 3.

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

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\begin{align*}
+-----------+       & +-----+ \\
|Sat term A |-Li)-- & |     | \\
+-----------+       & +-----+ \\
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**Figure 3: Network architecture for a reliable multicast with NC**

A multicast flow (M) is forwarded to both satellite terminals A and B. However packet Ni (resp. Nj) gets 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 other multicast or broadcast systems, such as NACK-Oriented Reliable Multicast (NORM) [RFC5740] or File Delivery over Unidirectional Transport (FLUTE) [RFC6726]. Note that both NORM and FLUTE are limited to block coding, none of them supporting sliding window encoding schemes [RFC8406].

### 3.3. Hybrid access

This use-case considers improving multiple path communications with network coding at the transport layer. We propose an illustration for this scenario in Figure 4. 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 [ETSI-TR2017].

To cope with packet loss (due to either end-user mobility or physical-layer impairments), network coding could be introduced both at the CPE and at the concentrator. Apart from packet losses, other gains could be envisioned, such as a better tolerance to out-of-order packets which occur when exploited links exhibit high asymmetry in
terms of RTT. Depending on the ground architecture
[I-D.chin-nfvrg-cloud-5g-core-structure-yang] [SAT2017], some
equipments might be hosting both SATCOM and cellular functions.

\(-{}-\) : bidirectional link

```
+--------+      +--------+   +--------+   +--------+   +--------+   +--------+
| SAT    |      | Backbone|   | Concentrator|   | Application|   | Function   |
+--------+      +--------+   +--------+   +--------+   +--------+   +--------+
```

Figure 4: Network architecture for an hybrid access using network coding

3.4. Dealing with LAN losses

This use-case considers the usage of network coding to cope with
cases where the end user connects to the satellite terminal with a
Wi-Fi link that exhibits losses. In the case of encrypted end-to-end
applications based on UDP, PEP cannot operate. The Wi-Fi losses
result in an end-to-end retransmission that would harm the quality of
experience of the end user. In this use-case, adding network coding
techniques could prevent the end-to-end retransmission from occurring.

The architecture is recalled in Figure 5.

\(-{}-\) : bidirectional link
\(-'-'-\) : Wi-Fi link

C : where network coding techniques could be introduced

```
+--------+      +--------+   +--------+   +--------+   +--------+   +--------+
| End    |      | Satellite|   | SAT     |   | Physical|   | Access   |   | Network  |
| User   |      | Terminal|   | Gateway |   | Gateway|   | Gateway  |
+--------+      +--------+   +--------+   +--------+   +--------+   +--------+
```

Figure 5: Network architecture for dealing with LAN losses
3.5. Dealing with varying channel conditions

This use-case considers the usage of network coding to cope with cases where channel condition change in less than a second and the mechanisms that are exploited to adapt the physical-layer codes (Adaptative Coding and Modulation (ACM)) may not adapt the modulation and coding in time: remaining errors could be recovered with higher layer redundancy packets. This use-case is mostly relevant when mobile users are considered or when the chosen band induces quick changes in channel condition (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.

The architecture is recalled in Figure 6.

--- : bidirectional link
C : where network coding techniques could be introduced

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

Figure 6: Network architecture for dealing with varying link characteristics

3.6. 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, packet losses can occur if the gateways are not properly synchronized or if the algorithm that is exploited to trigger gateway handovers is not properly tuned. During these critical phases, network coding can be added to improve the reliability of the transmission and allow a seamless gateway handover.

Figure 7 illustrates this use-case.
4. Research challenges

This section proposes a few potential approaches to introduce and use network coding in SATCOM systems.

4.1. On the joint-use of network coding and congestion control in SATCOM systems

SATCOM systems typically feature Performance Enhancing Proxy (PEP) RFC 3135. PEPs usually split end-to-end connections and forward transport or application layer packets to the satellite baseband gateway that deals with layer-2 and layer-1 encapsulations. PEP contributes to mitigate congestion in a SATCOM systems. PEP could host network coding mechanisms and thus support use-cases that have been discussed in this document.

Deploying network coding in the PEP could be relevant and independent from the specific characteristics of a SATCOM link. This leads to research questions on the interaction between network coding and congestion control.
4.2. On the efficient usage of satellite resource

The recurrent trade-off in SATCOM systems remains: how much overhead from redundant reliability packets can be introduced to guarantee a better end-user QoE while optimizing capacity usage? At which layer this supplementary network coding should be added?

This problem has been tackled in the past for physical-layer code, but there remains questions on how to adapt the overhead for, e.g., the quickly varying channel conditions use-case where ACM may not be reacting quickly enough.

4.3. Interaction with virtualized satellite gateways and terminals

Related to the foreseen virtualized network infrastructure, network coding 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 network coding VNF 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 efficient radio usage and easy-to-deploy SATCOM services. Moreover, another challenge related to a virtualized SATCOM equipment is the management of limited buffered capacities.

4.4. Delay/Disruption Tolerant Networks

Communications among deep-space platforms and terrestrial gateways can be a challenge. Reliable end-to-end (E2E) communications over such paths must cope with long delay and frequent link disruptions; indeed, E2E connectivity may be available only intermittently or never. 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 3.5 would legitimize 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 techniques 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 network coding can be integrated in the IETF DTN stack.

5. Conclusion

This document discusses some opportunities to introduce network coding techniques at a wider scale in satellite telecommunications systems.

Even though this document focuses on satellite systems, it is worth pointing out that 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 gathers 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.

6. Glossary

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

- ACM: Adaptive Coding and Modulation;
- BBFRAME: Base-Band FRAME - satellite communication layer 2 encapsulation works 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 Premises Equipment;
- COM: COMmunication;
- DSL: Digital Subscriber Line;
- DTN: Delay/Disruption Tolerant Network;
- DVB: Digital Video Broadcasting;
- E2E: End-to-end;
- ETSI: European Telecommunications Standards Institute;
7. Acknowledgements

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8. IANA Considerations

This memo includes no request to IANA.

9. Security Considerations

Security considerations are inherent to any access network, and in particular SATCOM systems. The use of FEC or Network Coding in SATCOM also comes with risks (e.g., a single corrupted redundant packet may propagate to several flows when they are protected together in an Inter-Flow coding approach, see section Section 3). However this is not specific to the SATCOM use-case and this document does not further elaborate on it.

10. Informative References

[ASMS2010]

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