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B. Adamson
NRL
C. Adjih
INRIA
J. Bilbao
Ikerlan
V. Firoiu
BAE Systems
F. Fitzek
TU Dresden
S. Ghanem
Independent
E. Lochin
ISAE - Supaero
A. Masucci
Orange
M-J. Montpetit
Independent
M. Pedersen
Aalborg University
G. Peralta
Ikerlan
V. Roca, Ed.
INRIA
P. Saxena
AnsuR Technologies
S. Sivakumar
Cisco
March 18, 2018

Taxonomy of Coding Techniques for Efficient Network Communications
draft-irtf-nwcrg-network-coding-taxonomy-08

Abstract

This document is the product of the Network Coding Research Group (NWCRG). It summarizes a recommended terminology for Network Coding concepts and constructs. It provides a comprehensive set of terms in order to avoid ambiguities in future IRTF and IETF documents on Network Coding. This document is in-line with the terminology used by the RFCs produced by the Reliable Multicast Transport (RMT) and FEC Framework (FECFRAME) IETF working groups.

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1. Introduction

This document is not an IETF product and is not a standard. This document is the product and represents the consensus of the Network Coding Research Group (NWCRCG). In 2017, it has been discussed during three audio conferences, each of them gathering 6 to 8 key experts, it has been co-edited, and finally subject to a RG Last Call. The general feeling was that the document was ready for the next step.

The literature on Network Coding research and system design, IETF included, led to a rich set of concepts and constructs. This document collects terminology used in the domain, both outside and inside IETF, provides concise definitions, and introduces a high-level taxonomy. Its primary goal is to be useful to IETF and IRTF activities. It is also in-line with the terminology already used by the RFCs produced by the Reliable Multicast Transport (RMT) and FEC Framework (FECFRAME) IETF working groups, in particular [RFC5052] [RFC5740] [RFC5775] [RFC6363] [RFC6726]. Note that in the definitions, the "(IETF)" tag indicates that the associated term is already used in IETF documents.

This document focuses on packet transmissions and packet losses. These losses will typically be triggered by various types of networking issues and/or impairments (e.g., congested routers or intermittent wireless connectivity). The notion of "packet" itself is multiform, depending on the target use-case and the notion of network (e.g., in which layer of the protocol stack does the coding middleware operate?). For instance, a "packet" may be a data unit to be carried as a UDP payload because the coding middleware is located between the application and UDP. In another configuration, coding may be applied within an overlay network and the notion of "packet" will be totally different. In any case the goals of Network Coding can be to improve the network throughput, efficiency, latency, and scalability, as well as providing resilience to partition, attacks, and eavesdropping (NWCRCG charter). Both End-to-End Coding and systems that also perform re-coding within intermediate forwarding nodes are considered in this document.

This document does not consider physical layer transmission issues, nor physical layer codes, nor error detection: if low layer error codes detect but fail to correct bit errors, or if an upper layer checksum (e.g., within IP or UDP) identifies a corrupted packet, then this packet is supposed to be dropped.

1.1. Requirements Language

The keywords "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. General definitions and concepts

This section gathers general definitions and concepts that are used throughout this document.

Packet Erasure Channel: A communication path where packets are either dropped or received without any error. This type of packet drop is referred to as an "erasure" or "loss". The term "channel" must be understood as a generic term for any type of communication technology (e.g., an Ethernet link, a WiFi network, or a full path between two nodes over the Internet). The "Erasure" channels are opposed to "Error" channels where one or multiple bit errors may happen during a packet transmission. These "Error" channels are out of scope.

Erasure Correcting Code (ECC), or (IETF) Forward Erasure Code (FEC):

A code for the Packet Erasure Channel (only). These codes are also called "Application-Level FEC" to highlight that they have been designed to be used within the higher layers of the protocol stack, to protect against packet losses. These codes are opposed to "Error" correction codes that are capable of identifying the presence and/or correcting bit errors. The "Error" correction codes are out of scope.

End-to-End Coding: A system where coding is performed at the source or (coding) middlebox, and decoding at the destination(s) or (decoding) middlebox. There is no re-coding operation at intermediate nodes. This is the approach followed in the FLUTE/ALC [RFC6726][RFC5775], NORM [RFC5740] and FECFRAME [RFC6363] protocols.

Network Coding: A system where coding can be performed at the source as well as at intermediate forwarding nodes (all or a subset of them). End-to-End Coding is regarded as a special case of Network Coding. Depending on the use case, additional assumptions can be made: for instance the knowledge by the destination of the coding nodes topology and coding operations can help during decoding operations.

Packet versus Symbol: Generally speaking, a Packet is the unit of data that is sent in the Packet Erasure Channel, while a Symbol is the unit of data that is manipulated during the encoding and decoding operations.

Original Payload, or Uncoded Payload, or Systematic Symbol, or (IETF) Source Symbol:

A unit of data originating from the source that is used as input to encoding operations. When there is a single Source Symbol per Source Packet, an Original Payload corresponds to a Source Packet.

Coded Payload, Coded Symbol, or (IETF) Repair Symbol: A unit of data that is the result of a coding operation, applied either to Source Symbols or (in case of recoding) Source and/or Repair Symbols. When there is a single Repair Symbol per Repair Packet, a Coded Payload corresponds to a Repair Packet.

Input Symbol and Output Symbol: A unit of data that is used as input to an encoding operation or that is generated as output of an encoding operation. At a re-coding node, Repair Symbols are also part of the Input Symbols. With Systematic Coding, Source Symbols are also part of the Output Symbols.

(IETF) Encoding Symbol: A Source or a Repair Symbol.

(En)coding versus Recoding versus Decoding: (En)coding is an operation that takes Source Symbols as input and produces Encoding Symbols as output. Recoding is an operation that takes Encoding Symbols as input and produces Encoding Symbols as output. Decoding is an operation that takes Encoding Symbols as input and produces Source Symbols as output.

(IETF) Source Packet: A packet originating from the source which contributes to one or more Source Symbols. For instance, an RTP packet as a whole can constitute a Source Symbol. In other situations (e.g, to address variable size packets) a single RTP packet may contribute to various Source Symbols.

(IETF) Repair Packet: A packet containing one or more Repair Symbols.

Figure 1 illustrates the relationships between packets (what is sent in the Packet Erasure Channel) and symbols (what is manipulated

during encoding and decoding operations) in case of FEC encoding, at a Coding Node that performs Encoding (rather than Recoding). FEC decoding procedures are similarly performed in the reverse order.

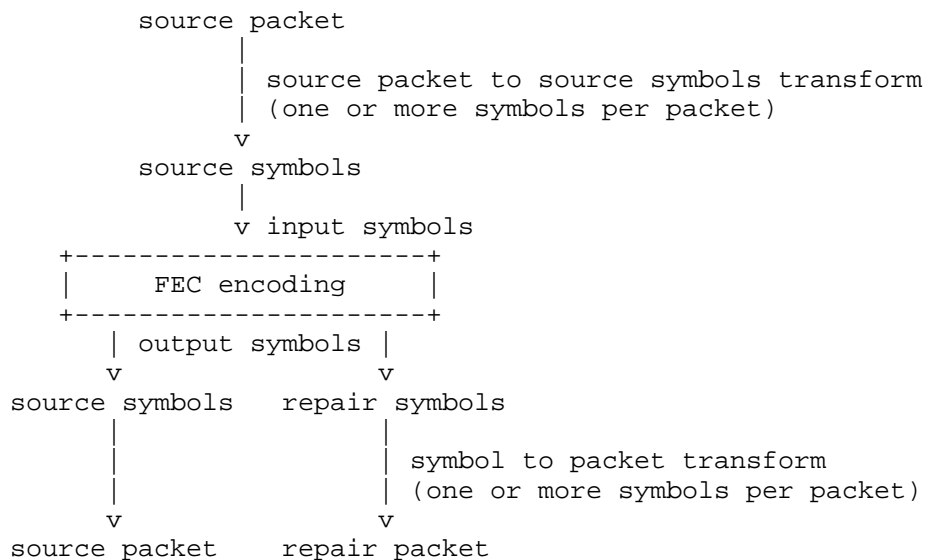


Figure 1: Packet and symbol relationships at a Coding Node that performs Encoding (rather than Recoding).

Source Node: A node that generates one or more Source Flows.

Coding Node: A node that performs FEC Encoding or Recoding operations. It may be an end-host or a middlebox (Encoding case), or a forwarding node (Recoding case).

(IETF) Flow: A stream of packets logically grouped.

(IETF) Source Flow: A flow of Source Packets coming from an application on a given host, and to which FEC encoding is to be applied, potentially along with other Source Flows. Depending on the use case, Source Flows may come from the same application, from different applications on the same host, or from different applications on different hosts.

(IETF) Repair flow: A flow containing Repair Packets, after FEC encoding.

3. Taxonomy of Code Uses

This section discusses the various ways of using coding, without going into coding details.

Source Coding versus Channel Coding: (see Figure 2) When both terms are opposed, "Source Coding" usually refers to compression techniques (e.g., audio and video compression) within the upper application that generates the source flow. On the opposite, "Channel Coding" refers to FEC encoding in order to improve transmission robustness, for instance within the lower physical layer (out of scope of this document) or as part of Network Coding. These terms should not be confused with respectively "FEC coding within the Source Node" and "FEC re-coding within an intermediate Coding Node".

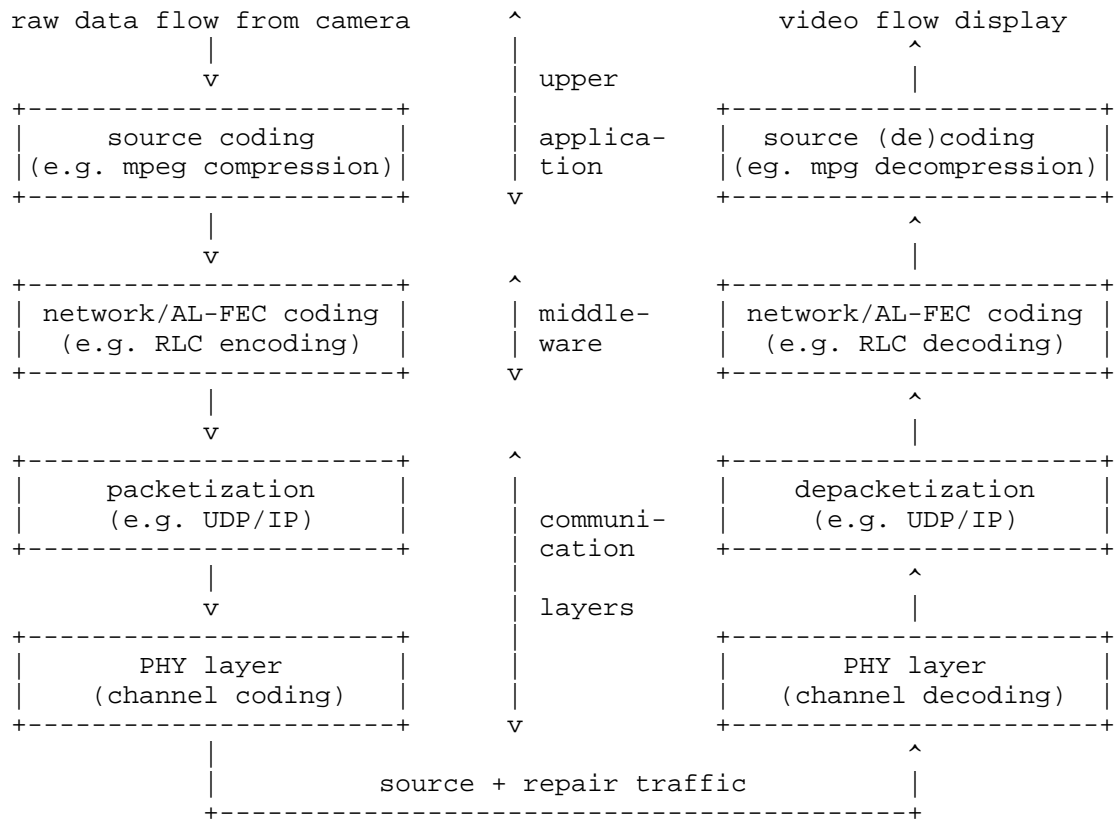


Figure 2: Example of end-to-end flow manipulation with Network Coding between the application and UDP layers (as with RMT or FECFRAME architectures). Other architectures are possible, for instance with network coding below the transport layer in order to allow re-coding within the network.

Intra-Flow Coding, or Single Source Network Coding: Process where incoming packets to the Coding Node belong to the same flow.

Inter-Flow Coding, or Multi-Source Network Coding: Process where incoming packets to the Coding Node belong to different flows.

Single-Path Coding: Network Coding over a route that has a single path from the source to each destination(s). In case of multicast or broadcast traffic, this route is a tree. Coding may be done end-to-end and/or at intermediate forwarding nodes.

Multi-Path Coding: Network Coding over a route that has multiple (at least partially) disjoint paths from the source to each given destination. Coding may be done end-to-end and/or at intermediate forwarding nodes.

4. Coding Details

4.1. Coding Types

This section provides a high-level taxonomy of coding techniques. Technical details are left for the following sections.

Linear Coding: Linear combination of a set of input symbols (i.e., Source and/or Repair Symbols) using a given set of coefficients and resulting in a Repair Symbol. Many linear codes exist that differ from the way coding coefficients are drawn from a Finite Field of a given size.

Random Linear Coding (RLC): Particular case of Linear Coding using a set of random coding coefficients.

Adaptive Linear Coding: Linear Coding that utilizes cross layer adaptation. For instance, an adaptive coding scheme may adapt the generation and transmission of Repair Packets according to the channel variations over time, accounting for the predictive loss of degrees of freedom due to erasures.

Block Coding: Coding technique where the input Flow(s) must be first segmented into a sequence of blocks, FEC encoding and decoding being performed independently on a per-block basis. The term "Chunk Coding" is sometimes used, where a "Chunk" denotes a block.

Sliding Window Coding, or Convolutional Coding: General class of coding techniques that rely on a sliding encoding window. This is an alternative solution to Block Coding.

Fixed or Elastic Sliding Window Coding: Coding technique that generates Repair Symbol(s) on-the-fly, from the set of Source Symbols present in the sliding encoding window at that time, usually by using Linear Coding. The sliding window may be either of fixed size or of variable size over the time (also known as "elastic sliding window"). For instance, this size may depend on acknowledgments sent by the receiver(s) for a particular Source Symbol or Source Packet (received, decoded, or decodable).

Systematic Coding: A coding technique where Source Symbols are part of the output Flow generated by a Coding Node.

Rateless and Non-Rateless Coding: Rateless Coding can generate an unlimited number of Repair Symbols (in practice this number can be limited by practical considerations or because of use-case requirements) from a given set of Source Symbols, meaning that the code rate is null. RLC codes are an example of Rateless Codes. On the opposite, Non-Rateless Coding usually has a predefined maximum number of Repair Symbols that can be generated from a given set of Source Symbols.

4.2. Coding Basics

This section discusses and defines low level coding aspects.

Code Rate: In case of a Block Code, the Code Rate is the k/n ratio between the number of Source Symbols, k , and the number of Source plus Repair Symbols, n . With a Sliding Window Code, the Code Rate is defined similarly over a certain time interval, since the Code Rate may change dynamically. By definition, the Code Rate is such that: $0 < \text{Code Rate} \leq 1$. A Code Rate close to 1 indicates that a small number of Repair Symbols have been produced during the encoding process and vice-versa.

(En)coding Window: A set of Source (and Repair in the case of re-coding) Symbols used as input to the coding operations. The set of symbols will typically change over the time, as the Coding Window slides over the input Flow(s).

(En)coding Window Size: The number of Source (and Repair in case of re-coding) Symbols in the current Encoding Window. This size may change over the time.

Payload Set: The set of Source and Repair Symbols available (i.e., received or previously decoded) at the receiver and used during FEC decoding operations.

Decoding window: The set of Source Symbols (only) that are considered in the current linear system of a receiver, independently of the fact these Source Symbols have been received, decoded, or lost. The Decoding Window will typically change over the time, as transmissions and decoding progress, and may be different for different receivers of a session where content is multicast or broadcast.

Decoding Window Size: The number of Source Symbols (only) in the current Decoding Window. This size may change over the time.

Rank of a Payload Set, or (IETF) Rank of the Linear System: At a receiver, number of linearly independent members of a Payload Set, or equivalently the number of linearly independent equations of the linear system. It is also known as "Degrees of Freedom". The system may be of "full rank" and decoding is possible, or "partial rank", and only partial decoding is possible.

Seen Payload, or Seen Symbol: A Source Symbol is Seen when the receiver can compute a linear combination with this symbol and Source Symbols that are strictly more recent (i.e., with logically higher Encoding Symbol Identifiers). Otherwise the Source Symbol is considered as "unseen".

Generation, or (IETF) Block: With Block Codes, the set of Source Symbols of the input Flow(s) that are logically grouped into a Block, before doing encoding.

Generation Size, or Code Dimension, or (IETF) Block Size: With Block Codes, the number k of Source Symbols belonging to a Block.

Coding Matrix, or Generator Matrix: A matrix G that transforms the set of Input Symbols X into a set of Repair Symbols: $Y = X * G$. Defining a Generator Matrix is usual with Block Codes. The set of Input Symbols X can consist only of Source Symbols (e.g., with End-to-End Coding) or can consist of Source and Repair Symbols (e.g., with re-coding in an intermediate node).

Coding Coefficient: With Linear Coding, this is a coefficient in a certain Finite Field. This coefficient may be chosen in different ways: randomly, or in a pre-defined table, or using a pre-defined algorithm plus a seed.

Coding Vector: A set of Coding Coefficients used to generate a certain Repair Symbol through Linear Coding. The number of nonzero coefficients in the Coding Vector defines its density.

Finite Field, or Galois Field, or Coding Field: Finite fields, used in Linear Codes, have the desired property of having all elements (except zero) invertible for $+$ and $*$ and all operations over any elements do not result in an overflow or underflow. Examples of Finite Fields are prime fields $\{0..p^m-1\}$, where p is prime. Most used fields use $p=2$ and

are called binary extension fields $\{0..2^m-1\}$, where m often equals 1, 4 or 8 for practical reasons.

Finite Field size, or Coding Field size: The number of elements in a finite field. For example the binary extension field $\{0..2^m-1\}$ has size $q=2^m$.

Feedback: Feedback information sent by a decoding node to a Coding Node (or from a receiver to a source in case of End-to-End Coding). The nature of information contained in a feedback packet varies, depending on the use-case. It can provide reception and/or FEC decoding statistics, or the list of available Source Packets received or decoded (acknowledgement), or the list of lost Source Packets that should be retransmitted (negative acknowledgement), or a number of additional Repair Symbols needed to have a Full Rank Linear System.

4.3. Coding In Practice

This section discusses practical aspects. Indeed, a practical solution must specify the exact manner encoding and decoding is performed but also all the peripheral aspects, for instance how an encoder informs a decoder about the parameters used to generate a certain Repair Packet (signaling).

(IETF) **FEC Scheme:** A specification that defines the additional protocol aspects required to use a particular FEC code. In particular the FEC Scheme defines in band (e.g., information contained in Source and Repair Packet header or trailers) and out of band (e.g., information contained in an SDP description) signaling needed to synchronize encoders and decoders.

Payload Indices, or (IETF) Encoding Symbol Identifiers (ESI): An identifier of a Source or Repair Symbol. If conceptually, each symbol is identified by a unique ESI value, in practice, with a continuous flow and a limited field size to hold the ESI, wrapping to zero is unavoidable and the same integer value will be re-used several times.

(IETF) **FEC Payload ID:** Information that identifies the contents of a packet with respect to the FEC Scheme. The FEC Payload ID of a packet containing Source Symbol(s) is usually different from that of a packet containing Repair Symbol(s). The FEC Payload ID typically contains at least an ESI.

Coding Vector and Encoding Window Signaling: With Sliding Window Codes, the FEC Payload ID of a Repair Packet contains information needed and sufficient to identify the Coding Vector and Coding Window. Concerning the Coding Vector, this may consist of a full list of Coding Coefficients (that may be compressed or not), or a piece of information (e.g., a seed) that can be used to generate the list of Coding Coefficients thanks to a predefined algorithm known by encoders and decoders (e.g., a Pseudo Random Number Generator, or PRNG), or an ESI that points to a given entry in a Generator Matrix in case of a Block Code. Concerning the Coding Window, this may consist of the full list of ESI of symbols in the Coding Window (that may be compressed or not), or the ESI of the first Source Symbol along with their number (assuming there is no gap).

5. IANA Considerations

This document is not subject to IANA registration.

6. Security Considerations

This document introduces a recommended terminology for network coding and therefore does not contain any security consideration. This does not mean that network coding systems do not have any security implication.

7. References

7.1. Normative References

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Appendix A. Additional references

Additional references on network coding are available in the NWCRG research web site: <https://irtf.org/nwcrg>

Appendix B. Authors and Contributors

This document is the result of a collaborative work that involved many authors and contributors from the IRTF NWCRG. They are listed in alphabetical order in this document.

Authors' Addresses

Brian Adamson
NRL
USA

Email: brian.adamson@nrl.navy.mil

Cedric Adjih
INRIA
France

Email: cedric.adjih@inria.fr

Josu Bilbao
Ikerlan
Spain

Email: jbilbao@ikerlan.es

Victor Firoiu
BAE Systems
USA

Email: victor.firoiu@baesystems.com

Frank Fitzek
TU Dresden
Germany

Email: frank.fitzek@tu-dresden.de

Samah A. M. Ghanem
Independant

Email: samah.ghanem@gmail.com

Emmanuel Lochin
ISAE - Supaero
France

Email: emmanuel.lochin@isae-supaero.fr

Antonia Masucci
Orange
France

Email: antoniamaria.masucci@orange.com

Marie-Jose Montpetit
Independant
USA

Email: marie@mjmontpetit.com

Morten V. Pedersen
Aalborg University
Denmark

Email:.mvp@es.aau.dk

Goiuri Peralta
Ikerlan
Spain

Email: gperalta@ikerlan.es

Vincent Roca (editor)
INRIA
France

Email: vincent.roca@inria.fr

Paresh Saxena
AnsuR Technologies
Norway

Email: paresh.saxena@ansur.es

Senthil Sivakumar
Cisco
USA

Email: ssenthil@cisco.com

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N. Kuhn, Ed.
CNES
E. Lochin, Ed.
ISAE
June 29, 2017

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 technics at a wider scale.

Status of This Memo

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This Internet-Draft will expire on December 31, 2017.

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1. Introduction

Network coding schemes are inherent part of the satellite systems, since the challenging physical layer require specific robustness to guarantee an efficient usage of the expensive radio resource. Further exploiting these schemes is an opportunity for a better end user experience along with a better exploitation of the scarce resource.

In this context, this memo aims at:

- o summing up the current deployment of network coding schemes;
- o identifying opportunities for further usage of network coding in satellite 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 XX: XX

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 of to provide a generic description of the components composing a generic satellite system and their interaction.

2.1. Generic description of multi-gateway satellite networks

This subsection presents a high level description of a multi-gateway satellite network.

2.2. Focus on satellite gateway description

This subsection focuses on the description of the functions that take place in a generic satellite gateway.

3. Status of network coding in actually deployed satellite systems

Figure 1 presents the status of the network coding deployment in satellite systems. The information is based on the taxonomy document [I-D.irtf-nwcrp-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).

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

Figure 1: Network coding and satellite systems

4. Opportunities for more network coding in satellite systems

This section extends Section 3 by presenting the opportunities for more network coding in satellite systems.

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5. Deployability and related use cases

This section details use-cases where the usage of network coding schemes could improve the overall system and the deployability of the opportunities that are provided in Section 4.

5.1. Network coding and VNF

Related to the foreseen virtualized network infrastructure, the network coding schemes could be proposed as VNF and their deployability enhanced.

5.2. Network coding and PEP

Related to the impact and integration of network coding in Proxy-Enhanced-Proxy RFC 3135 [RFC3135] architecture. In particular how network coding can be integrated inside a PEP with QoS scheduler as defined, for instance, in RFC 5865 [RFC5865].

6. Acknowledgements

7. Contributors

Many thanks to

8. IANA Considerations

This memo includes no request to IANA.

9. Security Considerations

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

10. References

10.1. Normative References

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Authors' Addresses

Nicolas Kuhn (editor)
CNES
18 Avenue Edouard Belin
Toulouse 31400
France

Phone: 0033561273213
Email: nicolas.kuhn@cnes.fr

Emmanuel Lochin (editor)
ISAE
10 Avenue Edouard Belin
Toulouse 31400
France

Email: emmanuel.lochin@isae.fr

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N. Kuhn, Ed.
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E. Lochin, Ed.
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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-nwcrg-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 UTRAN: 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.

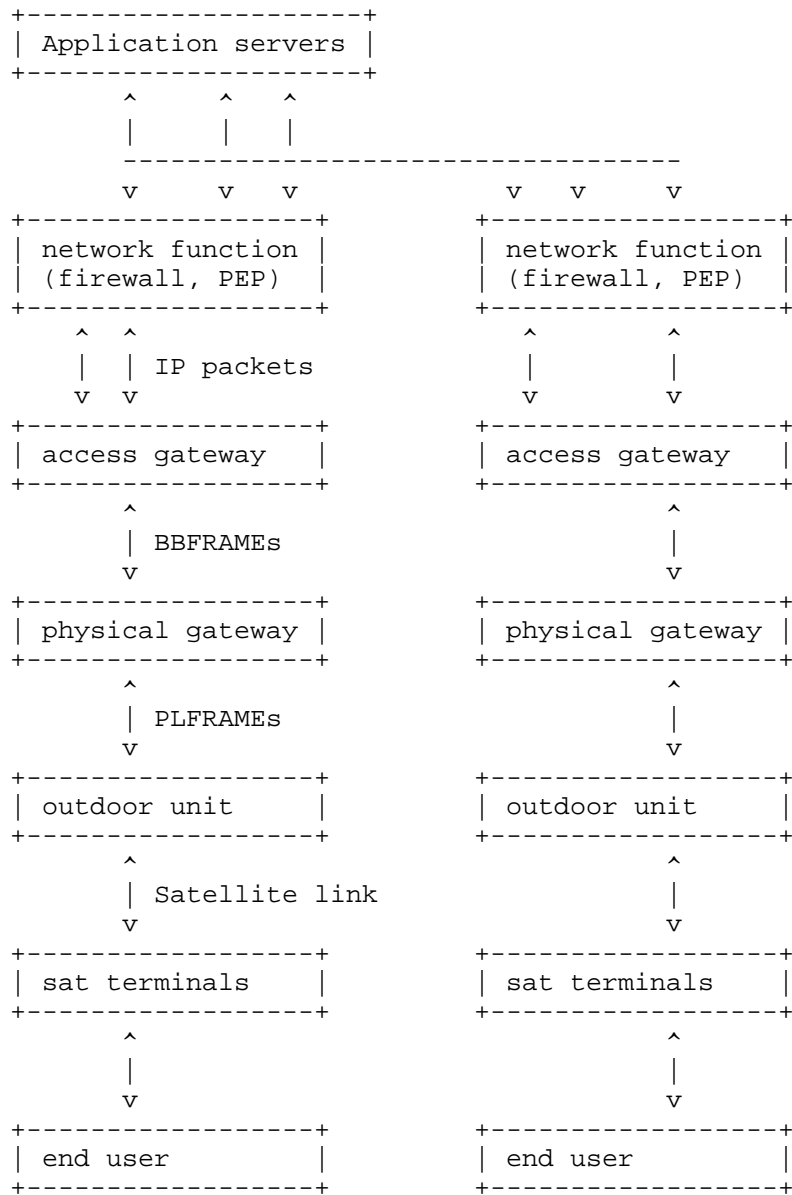


Figure 1: Data plane functions in a generic satellite multi-gateway system

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

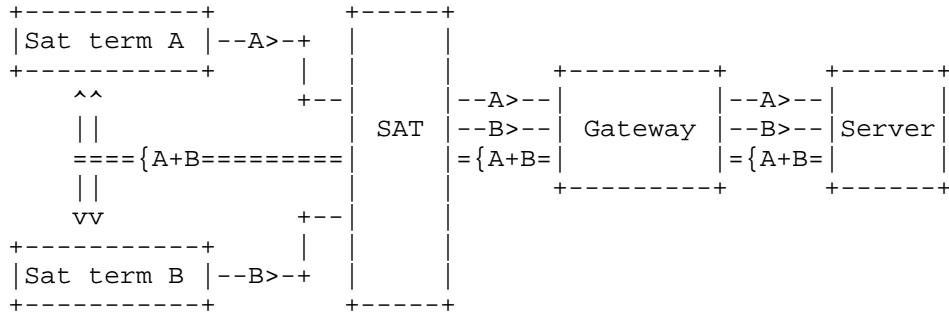


Figure 3: Network architecture for two way relay channel with NC

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

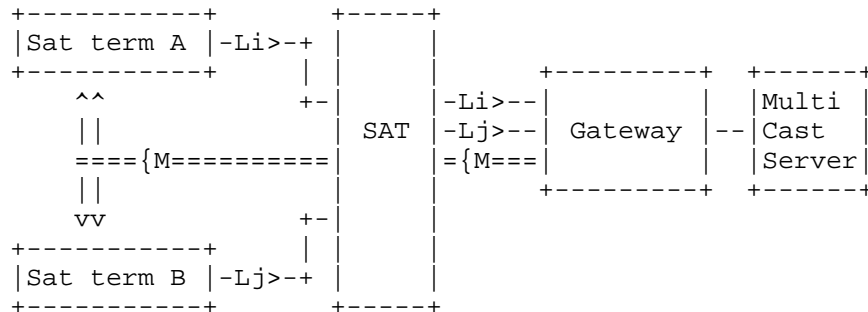


Figure 4: Network architecture for a reliable multicast with NC

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

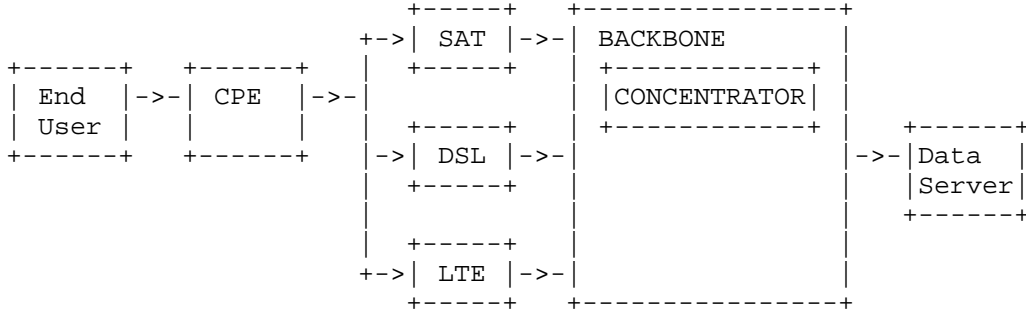


Figure 5: Network architecture for an hybrid access using NC

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

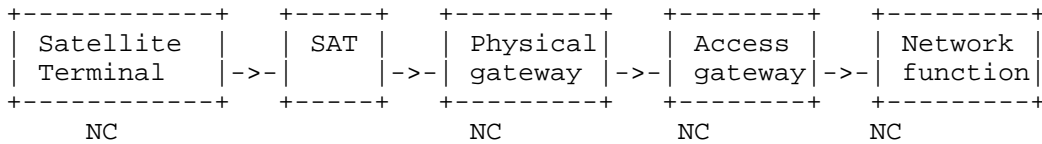


Figure 6: Network architecture for dealing with varying link characteristics with NC

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

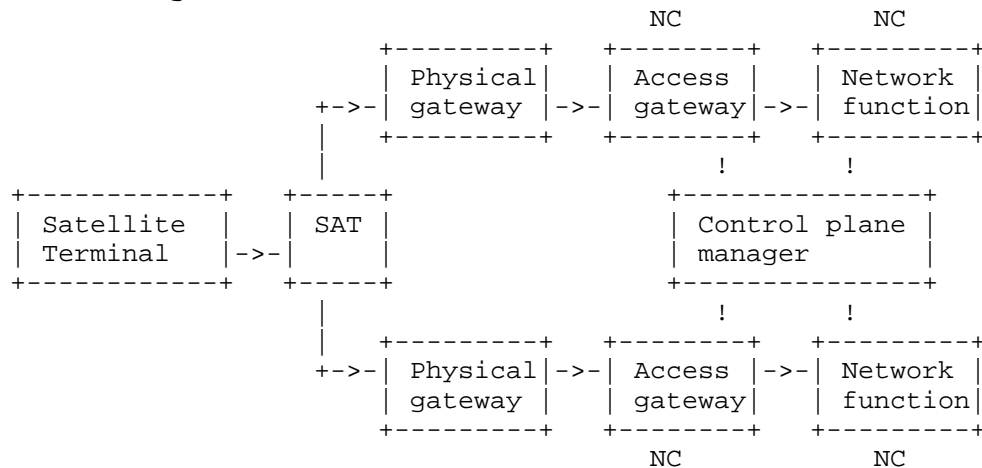


Figure 7: Network architecture for dealing with gateway handover schemes with NC

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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Authors' Addresses

Nicolas Kuhn (editor)
CNES
18 Avenue Edouard Belin
Toulouse 31400
France

Email: nicolas.kuhn@cnes.fr

Emmanuel Lochin (editor)
ISAE-SUPAERO
10 Avenue Edouard Belin
Toulouse 31400
France

Email: emmanuel.lochin@isae-supero.fr