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Network Coding Taxonomy

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Network Coding Taxonomy
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Abstract

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

Status of This Memo

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1. Introduction

The literature on Network Coding research and system design has a large set of concepts and contructs with origins in several research fields including Coding and Information Theory, Data Networks and Storage. In many cases, same or similar concepts have received multiple names, or the same name may be used for different concepts in different contexts. This document attempts to collect a comprehensive set of concepts and constructs, and for each, provide a concise definition along with a unique name that is most used and

most descriptive. This terminology will help avoid ambiguities in future Network Coding IRTF and IETF documents.

1.1. 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. The context of coding strategies

Source Coding Compressing the information at the source to increase the transmission efficiency by reducing redundant information [COMMENT: do we need this?]

Channel Coding Introducing redundant information in the transmission stream to increase reliability of communication.

Network Coding Coding operation realized at payload level and performed at the source as well as possibly at some intermediate nodes. This coding strategy can result in more efficient and more reliable communication.

3. Channel and error correction types

Packet Erasure Channel A communication path where packets are either dropped (e.g., by a congested router, or because the number of transmission errors exceeds the correction capabilities of the physical layer codes) or received. When a packet is received, it is assumed that this packet is not corrupted.

Packet Error Channel A communication path where packets are potentially subject to bit corruptions (that may not be corrected by the physical layer codes).

Network Error Correcting Code Method for correcting errors in communication networks by extending the classical error-correcting codes from a point-to-point model to networks.

Network Erasure Correcting Codes Method of using spatial redundancy of network coding to recover lost payloads.

4. Basics of Coding

Coding Field A pre-defined finite field used in a Network Coding algorithm or protocol. Coding fields have the desired property of having all elements invertible for + and * and all operations over any elements do not result in overflow/

underflow. Examples of finite fields are Galois fields, including prime fields {0..p^m-1}, where p is prime. Most used fields are binary fields {0..2^m-1}.

(Coding) Field size The number of elements in a field. For example the binary field {0..2^m-1} has size q=2^m.

(Coding) Elements Elements of a pre-defined coding field.

5. Payload-level Operations

Original (Uncoded) Payload A set of application-level data with defined byte sequence bounds, generated at the source of a flow. Original payloads are inputs to coding operations.

Alternative definition to Payload: Symbol A unit of data processed by a Network Coding operation. [COMMENT: we need to decide which to adopt or if we keep both]

Coded Payload The result of a coding operation applied to original or coded payloads.

Linear Coding Linear combination of a set of payloads using a given set of coefficients resulting in a coded payload. Payloads are divided in elements over a Coding Field. Elements at a given position from each payload are linearly combined. Resulting coded elements are assembled in a coded payload, respecting the original in-payload order. All linear combinations on any element position use the same given set of coefficients. The input payloads may be original (not coded) or coded. [COMMENT: Suggestion is to have a terse definition here and refer to a later section that will have more explanation of the algorithm and some diagrams.]

Non-linear Coding Combining a set of payloads using non-linear functions.

(Coding) Coefficient A coding element used as a coefficien t in linear coding of payloads.

Coding Vector A set of coding elements representing coefficients needed for generating a given coded payload through linear coding of original (non-coded) payloads.

Coding (or Generator) Matrix (of a set of coded payloads) A matrix G that transforms the set of source (uncoded) symbols X into a set of coded payloads Y = X * G.

Density of a coding vector Number of non-zero coefficents in the coding vector.

Random Linear Coding Linear coding using a set of random elements as coefficients

6. Network Coding Methods

Block coding Original payload sequence is divided in blocks, and coding is performed only over payloads within a block.

Sliding Window coding Given a stream of uncoded payloads, coding blocks are selected based on a sliding window. Coding blocks may be partially overlapping, and, over time, moving to higher original payload sequence numbers.

Elastic Window coding [Need definition]

Convolutional network coding Alternative solution to block network coding for cyclic networks where the results of propagation and coding of sequential payloads are similar to convolutional coding. [COMMENT: need a better definition.]

Coding node Node performing coding operations.

7. Payload-level Operations in Block Coding Method

(Coding) Block a.k.a. Generation A set of (usually consecutive) original (uncoded) payloads defined by the sender-side of an NC transport protocol. Coding is only performed over payloads belonging to the same block. Payloads resulting from coding over payloads of a block, also belong to the same block.

(Coding) Block size a.k.a. Code dimension The number of original payloads belonging to a coding block

Code rate The ratio k/n between the number of source symbols k and the number of encoding symbols n. By definition, the code rate is such that: 0 < code rate <= 1. A code rate close to 1 indicates that a small number of repair symbols have been produced during the encoding process.

(Coded) Payload Set A set of payloads belonging to the same block, usually received at a node.

Rank of a Payload Set The number of linearly independent members of a Payload Set received at a node. Also known as "Degrees of

Freedom". [COMMENT: May need to revise and refer to an associated linear system.]

Full Rank The condition that a Payload Set received at a node has rank equal to the block's size. A Payload Set can be fully decoded into original packets iff it has full rank.

Partial Rank Any rank that is less than full rank and not zero.

8. Node-local Processing in Block Coding Method

NACK A message from a node that the linear system associated to the received Payload Set does not have full rank, and additional source or repair symbol(s) is(are) needed.

Range Space of a Payload Set The linear space defined by the coding vectors of a Payload Set.

Null Space The linear space that represents the complement of the Range Space of a Payload Set.

Null Space Sample A coding vector that is included in the Null Space.

Solvable Payload Set The set of original payloads that can be decoded from a given set of coded payloads.

9. Node-local Processing in Sliding Window Coding Method

Payload Indices The original payloads are numbered with indices 1,2, . . . N

Sliding (encoding) window [Sun08] [Lac08] A set of consecutive indices of original payloads: a node generates coded payloads that are linear combinations of original payloads with indices in its current sliding window.

Sliding window size [Lin10] [Cho08] [Sun09] The number of consecutive payload indices of the window

Seen payload (original payload seen at a receiver) [Sun08] [Sun09] [Lin10] [Bao12] An original payload is "seen", when the receiver can compute a linear combination with this payload and original payloads with only higher indices. Otherwise the payload is unseen.

Sensed payload (original payload sensed at a receiver) [Bao12] At a receiver, an original payload is "sensed" when it is present

in at least in one of the received coded payloads. Otherwise it is unsensed.

Lowest/ highest index of coded payloads [Cho08] The minimum (resp. maximum) index of original payloads involved in a coded payload.

10. Network Coding Transport

Coherent Network Coding Source and destination nodes know network topology and coding operations at intermediate nodes. [COMMENT: Need to clairify what "know" means.]

Noncoherent Network Coding Source and destination nodes do not know network topology and intermediate coding operations. In this case, random network coding can be applied.

Flow A stream of packets logically grouped from the network coding perspective. These packets may come from the same application (in that case they are identified by the five-tuple: source and destination IP address, transport protocol ID, and source and destination port of the transport protocol), or come from the same source host (in which case they are identified by the 3-tuple source and destination IP address, Type of Service (TOS) or Diffserv code point (DSCP)). This distinction depends on the use-case where network coding is applied.

Intra-flow coding Network coding over payloads belonging to the same flow.

Inter-flow coding Network coding over payloads belonging to multiple flows.

End-to-end coding Transport stream is coded and decoded at end-points.

Intermediate coding Packet coding can occur at endpoints and any intermediate nodes on the route.

Coding node Node performing coding operations.

Forwarding factor The rate of transmission from a node relative to the rate of information received at the same node.

11. Routing and Forwarding

Single-Path route A route that has a single path from source to destination(s). In case of multicast, this is a tree.

Multi-Path route A route containing multiple disjoint paths from source to a destination.

Subgraph A generalized multi-path route from a sender to one or multiple receivers where paths can intersect and diverge any number of times.

Forwarding The process of conveying a flow from the current node or previous hop(s) to the next hop(s) along single- or multi-path routes. Coding operations may be performed during the forwarding process when network coding is applied within intermediate nodes.

12. Acknowledgements

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13. IANA Considerations

This memo includes no request to IANA.

14. Security Considerations

This memo includes no Network Coding - specific security definitions yet.

15. References

15.1. Normative References

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