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Network Coding Function Virtualization
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Abstract

This document describes network coding as a network function. It also describes how a network coding function can be virtualized and integrated with virtual network functions architectures. The network coding function is not a traditionally implemented network function in dedicated hardware as those that have triggered network function virtualization. It refers to a novel network functionality that generalizes classic packet-level end-to-end coding. Classic packet-level end-to-end coding helps in the provision of quality of service by trading off delay and reliability. Network coding goes beyond that by enabling in-network optimized re-encoding, which can provide both throughput gains and diverse network-controlled degrees of reliability. Consequently, a virtualized network coding function can serve as a flow engineering tool over virtualized networks (e.g. over network slices).

Status of This Memo

This Internet-Draft will expire on May 17, 2017.

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1. Introduction

Network coding(NC) is a novel technology that can be seen as the generalization of classic point to point coding to coding for network flows. As with classic coding, both information theoretical and algebraic codes literature provide the conceptual solid basis of NC. Such conceptual basis has clarified NC benefits and corresponding tradeoffs, which need to be considered in practical implementations of the technology.

NC does not replace end-to-end (packet-level block) coding, which is a well-established technology for the per-flow provision of quality of service by trading off delay and reliability. Instead, NC provides coding within and across network flows relying on in-network

re-encoding based on service-intent-oriented policy strategies. By means of such policy strategies, the provision of quality of service that NC can offer can be tailored according to desired network service intent.

For its operation, NC relies on having access to network, computation and storage resources throughout the network. Such novel networking, computational and storage ingredients of a coding technology calls for novel practical design approaches to truly exploit the potential capabilities of NC.

On the other hand, Network Function Virtualization (NFV) and NC can be seen as different ways to address different challenges in the design of upcoming network technologies. Moreover, NC is not a traditionally implemented network function in dedicated hardware, which are the network functions that have triggered the design of NFV architectures. However, in this document we show the feasibility and benefits of virtualizing the network coding function.

The objective of this document is not to explain network coding technology. The interested reader should find this information outside this document.

The objective of this document is fundamentally two fold. First, we show that NC can be designed as a (modular) network function. The modularity is convenient for the user and is given as sets of elementary functionalities (toolboxes) that are defined independent of the physical network. Second, we show that the NC function requirements of connectivity, computation and storage resources find a natural practical design solution in the integration of the NC function with available NFV architectural frameworks. Such solution is described here and it combines network protocol-driven and system modular-driven design approaches.

The resulting Virtual Network Coding Function (VNCF) can be useful for upcoming networking needs derived from network virtualization.

2. Conventions used in this document

The following terms defined in this document can be found in the ETSI NFV [etsi_gs_nfv_002_v1.2.1] and the IETF [I-D.irtf-nwcrg-network-coding-taxonomy].

Coherent Network Coding: Source and destination nodes know network topology and coding operations at intermediate nodes.

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 physical 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.

Coding node: Node performing coding operations.

Virtualized Infrastructure Manager (VIM): functional block that is responsible for controlling and managing the NFVI compute, storage and network resources, usually within one operator's Infrastructure Domain.

Virtualized Network Function (VNF): implementation of a Network Function that can be deployed on a Network Function Virtualization Infrastructure (NFVI).

Virtualized Network Function Manager (VNFM): functional block that is responsible for the lifecycle management of VNF.

NFV Infrastructure (NFVI): totality of all hardware and software components which build up the environment in which VNFs are deployed.

NFV Orchestrator (NFVO): functional block that manages the Network Service (NS) lifecycle and coordinates the management of NS lifecycle, VNF lifecycle (supported by the VNFM) and NFVI resources (supported by the VIM) to ensure an optimized allocation of the necessary resources and connectivity.

NFV Management and Orchestration (NFV-MANO): functions collectively provided by NFVO, VNFM, and VIM.

3. Network coding as a network function

NC design involves different domains. We can identify at least three domains:

Coding domain - domain for the design of network coding codebooks, coherent or noncoherent encoding/decoding schemes, performance benchmarks, appropriate mathematical-to-logic maps, etc. This is a domain fundamentally designed by coding theorists.

Functional domain - domain for the design of the functional properties of NC to achieve the desired design requirements upon abstractions of networks and systems. This domain jointly requires to consider physical-logical abstraction, identification of network coding application to either inter-flow or intra-flow network coding, service intent and related networking for the provision of quality of service.

Protocol domain - domain for the design of physical signaling/ transporting of the network coded information flow as one way or interactive protocols.

The functional domain can be designed interpreting NC as a network function. In order to provide the designer with sufficient flexibility, NC elementary functionalities can be grouped as a set of toolboxes that the designer can use. We define the following three toolboxes:

- Coding/Re-encoding/Decoding Functionalities (CRDF).

- Flow Engineering Functionalities (FEF) performing optimization of available network resources to optimally perform NC to meet the service design targets depending on the (statistical) status of the networks (congestion, link failures, etc).

- Physical/Abstraction Functionalities (PAF) performing interaction with available storage and computation physical resources that are abstracted by the other toolboxes.

4. Virtual Network Coding Function

4.1. Virtualization of flows

An important differentiating aspect of NC with respect to traditional networking technologies is the following. A network flow for a NC network function is understood as a stream of physical packets logically grouped from the network coding perspective.

NC can optimize the NC operation abstracting such physical flow as a mathematical model, which can be subject of computational manipulation. This makes NC to be naturally integrated into a virtualized framework of abstract entities such as virtual network or network slices. This is because in the NC case, not only the network and resources are abstracted, but also the stream of packets is abstracted.

Consequently, when interpreting NC as a functionality provided to the network, NC function virtualization simply consists of integrating the NC functional toolboxes described in the previous section into existing architectural NFV frameworks. The virtualization of the network flow is managed by the NC function (CRDF toolbox), and the virtualization of all the functionalities described in Section 3 has no difference with respect to any other network function.

4.2. Integration with ETSI NFV architecture

Figure 1 shows our proposed virtual NC network function (VNCF). It is integrated with the ETSI NFV architecture given the abstracted underlying physical system/network as part of NFVI.

The integration naturally includes too exchanges between VNCF and NFV-MANO over reference points.

Clearly, the functionalities of the FEF toolbox need to interact with the NFVO, VNFM, and VIM. Note that the NFVO two main responsibilities of orchestration of NFVI resources across VIMs and the life-cycle management of network services, fit perfectly the needs of the FEF and PAF toolboxes. Specifically, the FEF can obtain available network, connectivity and computation resources, geo-statistical status of the networks such as congestion, link failures, etc. With these, NC operation can be optimized to meet the service design targets given the service-specific design constraints. The optimization may result into manipulation of the (non-physical) flows and other flow engineering policies. On the other hand, the FEF can interact with the VIM to obtain the allocation, upgrade, release, etc of NFVI resources.

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        +--------------------------------------------+  +---------------+
        |   Virtualized Network Functions (VNFs)     |  |               |
        |  -------   -------   -------   -------     |  |               |
        |  |     |   |     |   |     |   |     |     |  |               |
        |  | VNF |   | VNF |   |VNCF |   | VNF |     |  |               |
        |  |     |   |     |   |     |   |     |     |  |               |
        |  -------   -------   -------   -------     |  |               |
        +--------------------------------------------+  |               |

        +--------------------------------------------+  |               |
        |         NFV Infrastructure (NFVI)          |  |      NFV      |
        | -----------    -----------    ----------- |  |  Management   |
        | | Virtual |    | Virtual |    | Virtual | |  |      and      |
        | | Compute |    | Storage |    | Network | |  | Orchestration |
        | -----------    -----------    ----------- |  |               |
        | +----------------------------------------+ |  |               |
        | |         Virtualization Layer           | |  |               |
        | +----------------------------------------+ |  |               |
        | +----------------------------------------+ |  |               |
        | | -----------  -----------  ----------- | |  |               |
        | | | Compute |  | Storage |  | Network | | |  |               |
        | | -----------  -----------  ----------- | |  |               |
        | |          Hardware resources            | |  |               |
        | +----------------------------------------+ |  |               |
        +--------------------------------------------+  +---------------+
```

Figure 1: ETSI NFV framework with one VNCF box as part of the set of available VNFs.

4.3. Example

We describe here a high-level example of a general procedure of interaction between the VNCF and the NFV-MANO. The NFV-MANO has repositories that hold different information regarding network services (NSs) and VNFs (VNCF is part of VNFs). There are four types of repositories as follows:

- o VNF catalogue represents the repository of all usable VNF packages, supporting the creation and management of the VNF packages.

- o NS catalogue represents the repository of all usable NSs.

- o NFV instances is the repository that holds details of all VNF instances and NS instances, represented by either a VNF record or a NS record, respectively, during the execution of VNF/NS life-cycle management operations.

o NFVI resources is the repository that holds information about NFVI resources utilized for the establishment of NS and VNF instances.

Assume a network abstracted as a set of N coding nodes, each with encoding/re-encoding/decoding and (possibly) multi-link connectivity. A user of the VNCF wants to provide an ultra-reliable service (e.g. mission-critical communications) to the N nodes. The performance objectives are given as a set of N reliability and delay objective performance metrics, which are geo-location dependent. We call this VNCF instantiation as a virtual geo-network coding function (VGNCF), which is activated and its management and orchestration take place.

A detailed interaction with the architectural blocks (some under definition) is as follows.

o TBD

5. Conclusions

This memo presents a preliminary version of proposal for the design of NC as a network function. It is also discussed that it can be virtualized and integrated into a NFV architecture.

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2. SatNetCode - Satellite Network-Coding for high performance, semantic-aware mission-critical visual communications. This project is funded by the European Space Agency.

3. HENCSAT - Highly Efficient Network Coding for Satellite Applications Test-bed. This project is funded by the European Space Agency.

7. IANA Considerations

This memo includes no request to IANA.

8. Security Considerations

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

9. References

9.1. Normative Information References

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