Virtual Network Coding Function

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Objectives

1. Concept of network coding.
2. Design of network coding as a VNF.
3. Get feedback from NFVRG.

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Concept

Theorem (Elias, Feinstein, Shannon, 1956). Max-flow Min-cut.

Maximum amount of information flow passing from source *s* to sink *t* is equal to the capacity of the minimum cut-set.

-Based on energy conservation law.

-Basis of current Internet, store-and-forward nodes.

Theorem (Ahlswede, Cai, Li, Yeung, 2000). Multicast Max-flow Min-cut.

Maximum amount of information flow passing from a source s to every ti multicast destination is equal to the minimum value among all cut-sets.

-NOT based on energy conservation law.

-NOT based on store-and-forward, but on network coding.

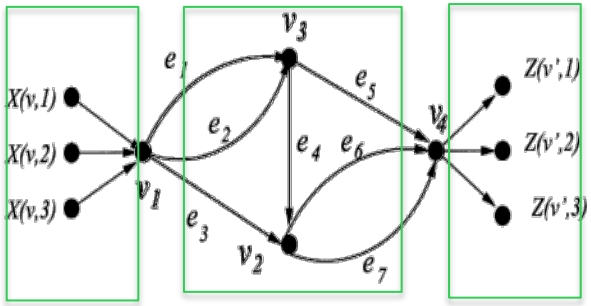
Li et Al. (2003) and Ho et Al. (2003/06)
Koetter, Medard (2002/03)

- Linear coding is enough to achieve multicast capacity.

$$P_i^{(\text{out})} = \sum_{j=1}^{m} a_{ij} P_j^{(\text{in})}.$$

- Random linear coding (random selection of a_{ij}) is enough to achieve multicast capacity.

- Purely algebraic coding solvability. Networking becomes solving linear relations between input flows (X) and output flows (Z).



Z=MX Z=MX Z=MX

$M = ATB^T$

$$A = \begin{pmatrix} \alpha_{e_1,1} & \alpha_{e_2,1} & \alpha_{e_3,1} \\ \alpha_{e_1,2} & \alpha_{e_2,2} & \alpha_{e_3,2} \\ \alpha_{e_1,3} & \alpha_{e_2,3} & \alpha_{e_3,3} \end{pmatrix}$$

$$B = \begin{pmatrix} \varepsilon_{e_5,1} & \varepsilon_{e_5,2} & \varepsilon_{e_5,3} \\ \varepsilon_{e_6,1} & \varepsilon_{e_6,2} & \varepsilon_{e_6,3} \\ \varepsilon_{e_7,1} & \varepsilon_{e_7,2} & \varepsilon_{e_7,3} \end{pmatrix}$$

$$M = A \begin{pmatrix} \beta_{e_1,e_5} & \beta_{e_1,e_4}\beta_{e_4,e_6} & \beta_{e_1,e_4}\beta_{e_4,e_7} \\ \beta_{e_2,e_5} & \beta_{e_2,e_4}\beta_{e_4,e_6} & \beta_{e_2,e_4}\beta_{e_4,e_7} \\ 0 & \beta_{e_3,e_6} & \beta_{e_3,e_7} \end{pmatrix} B^T$$

From R. Koetter and M. Médard, "An algebraic approach to network coding", 2003.

General benefits and cost

- Increases throughput, reduces delay.
- Better use of network resources (efficiency).
- Reduced computational complexity compared to routing.
- Robustness to/detection of link failures.
- Enables in-network engineering of packet flows.
- The concept of network coding can be applied at any communication layer, including physical layer.

- Additional overhead due to coding coefficients.
- Requires novel design paradigms and possibly gradual implementation/deployment.
- Patents for some things in some countries.

Examples

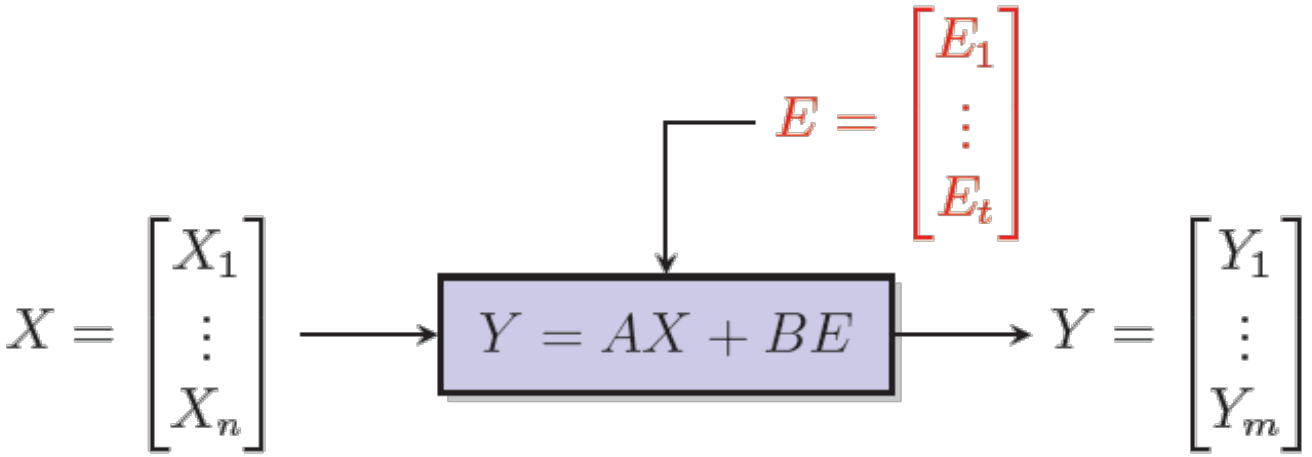
- TCP/IP native leads to network congestion
  - NC enables faster TCP and lower congestion.
- P2P file sharing/content distribution
  - Avalanche (Microsoft): BitTorrent-like with NC.
    - Big file to randomly coded small pieces .
    - Participants share coded pieces.
  - Higher throughput, easy scheduling, lower delay.
- Instant messaging
  - Alternative to flooding (informative packets).
- (Passive) network tomography
  - Topology inference.
- Distributed storage.

Types of errors in network-coded networks

- Random errors
  - Tackled classically on a link-by-link basis.
  - Either errors are corrected or the packet is discarded.
- Erasure errors
  - Due to underlying protocols (e.g. congestion).
- Malicious nodes
  - Packets may be altered by malicious nodes.
  - Exogenous packets may be injected to interfere communication.
- Errors in headers
  - Any error in the header may cause crucial information to be lost.
- Different approaches

Non-coherent approach: Kötter, Silva, Kschischang, 2008-2011

- Two separated problems ("non-coherent"):
  - Network coding problem.
  - Error correction problem.
- Network matricial channel (linear operator channel)



- Adversarial error model.

Constructions

- Subspace coding (codewords are subspaces!).
- Novel construction approaches, e.g.:
  - With certain automorphism group. Etzion, Vardy, 2011.
  - Spread codes. Manganiello, Gorla, Rosenthal, 2008.
  - Orbit codes. Magianello, Trautmann, Rosenthal, 2011.
  - Based on Schubert Calculus and Plücker coordinates. Trautmann, Silberstein, Rosenthal, 2013.
  - Multilevel construction. Etzion, Silberstein, 2009.
  - Constructions based on q-analog designs.

Full list at www.network-coding.eu/

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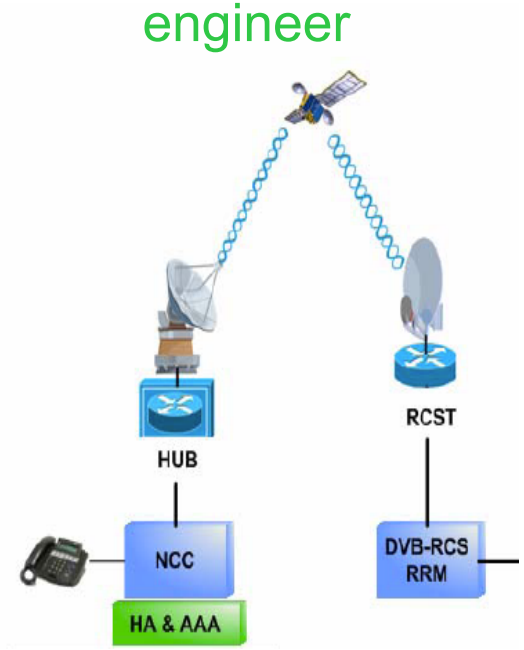
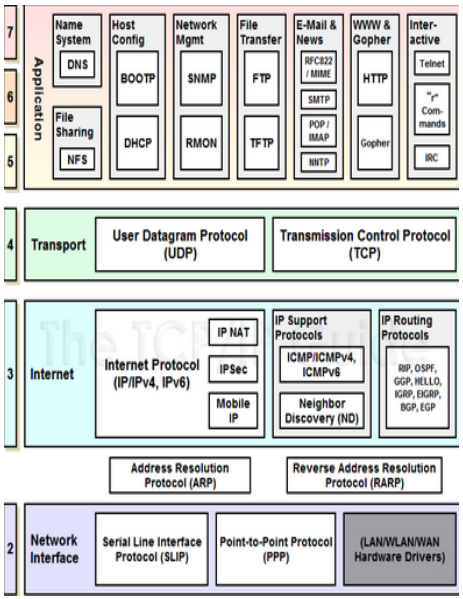
From coding to networking

Telecom engineer



Networking/computer scientist

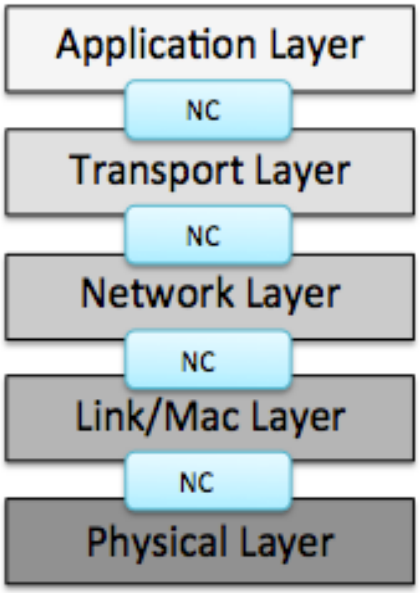


Theoretical computer scientist

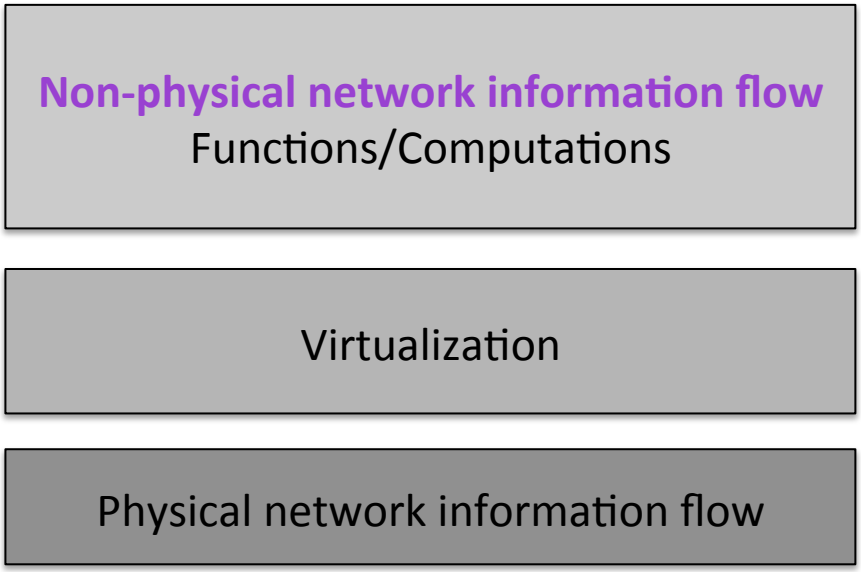
Coding theorist/ algebraist

From coding to networking

Today



Coming up
(Network coding view)



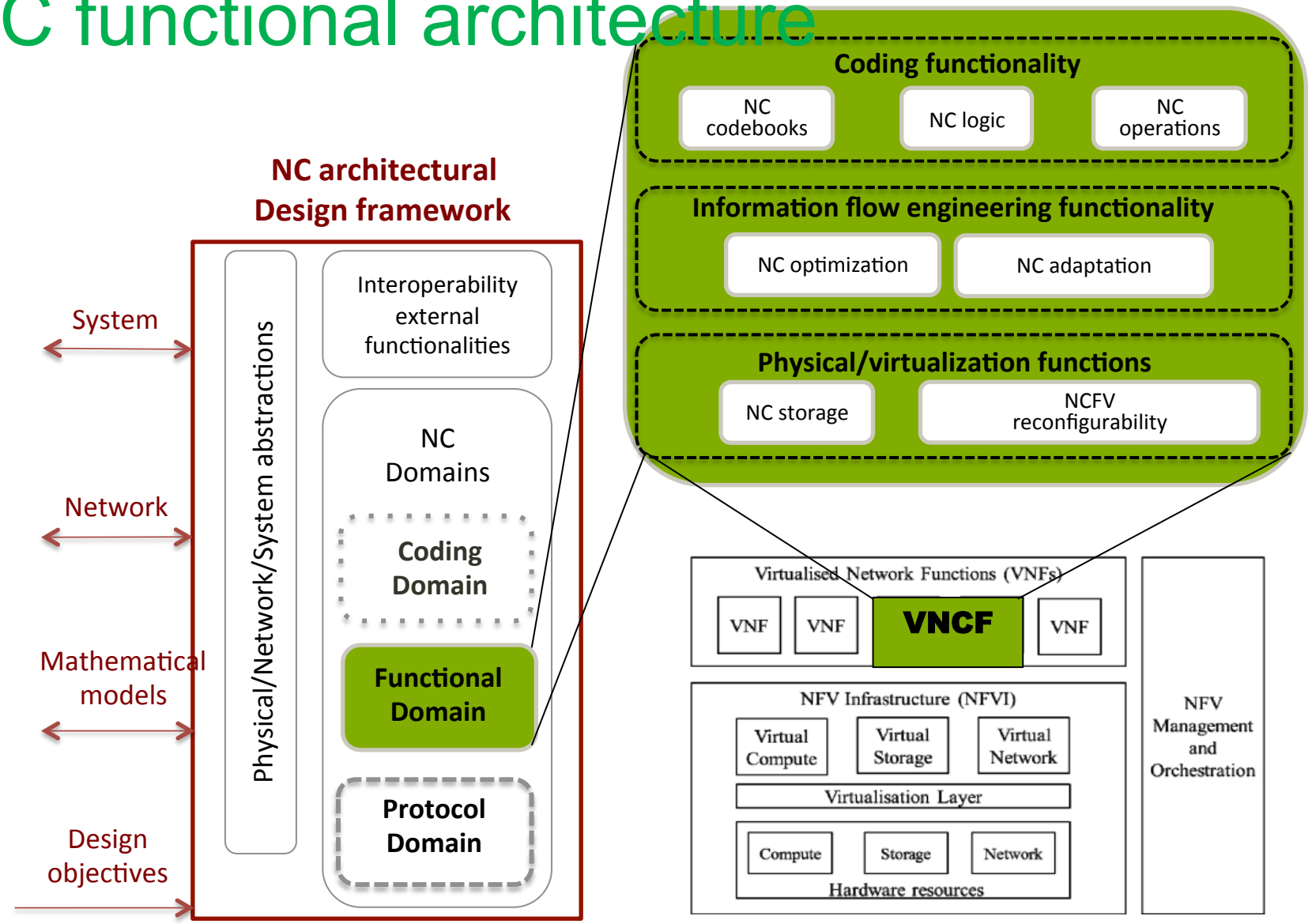
Proposal: network coding functional architecture

- Follow up of ideas in NWCRG.
- European COST Action on network coding
- Invited SPAWC'16 paper
  - "Network Coding Function Virtualization"
- NetWorld2020 whitepaper
  - Support to 5G PPP initiative.
- Validating scenario
  - Geo-Vision H2020 project.

Proposal: network coding functional architecture

- Approach combines
  - System-oriented (ITU/ETSI).
  - Network-oriented (e.g. IETF/IRTF).
- Functional architecture (preliminary ideas presented at NWCRG)
  - Coding functionalities:
    - Logical interpretation of coding use.
    - Coding for flow computation/manipulation.
  - Information flow engineering functionalities
    - Adaptation.
    - Optimization
      - Resource Allocation.
      - Spatial computation.
  - Physical/virtualization functionalities
    - Storage, interaction physical/virtual.

NC functional architecture



Validation scenario

- H2020 Geo-Vision project: geo-network coding solutions for communications involved in UN operations, civil protection and law enforcement.

- Galileo-based geo-spatial control of reliability .
  - Coding functionality: systematic network coding.
  - Optimization functionality based on reducing energy consumption and complexity.
  - Analytical (spatial) model for orchestration.

To take home

- Network coding and coding for network coding are both coding concepts and networking design tools.
  - Check codes at www.network-coding.eu/ .
- Applicable to real packet networks for the control and optimization of the information flow.
  - Across layers.
  - Across networks.
- Functional architecture enables the design of virtual network coding function(s).

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