Network Coding for Future Communication and Storage Systems

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Overview

• History of Networks
• Key Technology: Network Coding
  – Why RANDOM is so important?
  – What makes NC different than other codes?
• Implementation of NC
• Distributed Storage, Transport and SDN
The Telephone System

• Voice oriented
• Starting in 1876 and onwards
• One line per communication partner
• Star architecture
• Later circuit switched
The Telephone System
The Telephone System
The Telephone System
The Internet

- Paul Baran 1960s

Not Evolution, but Revolution
(Disintergration of circuit)
The Internet

• Multiple Service
• Packets do not have to follow a given route and can change the route on the fly
• In practise single path communication
• Not good for security
• Not exploiting full potential of the network
Single Path vs Multi Path

• Comparison with the brain
• Our brain uses multi paths
  – Reliability (Pain)
The Coded Internet

- Wireless meshed networks
  - IoT/M2M/D2D
- Storage and cloud services
- Content centric networks

Not Evolution, but Revolution

Compute and forward
(Disintergration of packet)

- Throughput
- Reliability
- Delay
- Security
- Complexity

5G
Random Linear Network Coding

\[
\begin{pmatrix}
C_1 \\
C_2 \\
C_3 \\
C_4 \\
C_5 \\
C_6 \\
\end{pmatrix}
= 
\begin{pmatrix}
\alpha_{1,1} & \alpha_{1,2} & \alpha_{1,3} & \alpha_{1,4} & \alpha_{1,5} & \alpha_{1,6} \\
\alpha_{2,1} & \alpha_{2,2} & \alpha_{2,3} & \alpha_{2,4} & \alpha_{2,5} & \alpha_{2,6} \\
\alpha_{3,1} & \alpha_{3,2} & \alpha_{3,3} & \alpha_{3,4} & \alpha_{3,5} & \alpha_{3,6} \\
\alpha_{4,1} & \alpha_{4,2} & \alpha_{4,3} & \alpha_{4,4} & \alpha_{4,5} & \alpha_{4,6} \\
\alpha_{5,1} & \alpha_{5,2} & \alpha_{5,3} & \alpha_{5,4} & \alpha_{5,5} & \alpha_{5,6} \\
\alpha_{6,1} & \alpha_{6,2} & \alpha_{6,3} & \alpha_{6,4} & \alpha_{6,5} & \alpha_{6,6} \\
\end{pmatrix}
\begin{pmatrix}
P_1 \\
P_2 \\
P_3 \\
P_4 \\
P_5 \\
P_6 \\
\end{pmatrix}
\]

Gaussian elimination \( n \times n \) matrix requires \( An^3 + Bn^2 + Cn \) operations.
Random Linear Network Coding

Gaussian elimination $n \times n$ matrix requires $A n^3 + B n^2 + C n$ operations.
Random Linear Network Coding

Gaussian elimination $n \times n$ matrix requires $An^3 + Bn^2 + Cn$ operations.
RLNC Features

Multiple encoding schemes

Block Coding:

\[ \begin{align*}
1 &= a_1 \Sigma_1 + b_1 \Sigma_2 + g_1 \Sigma_3 \\
2 &= a_2 \Sigma_1 + b_2 \Sigma_2 + g_2 \Sigma_3 \\
3 &= 1 + b_3 \Sigma_2 + g_3 \Sigma_3
\end{align*} \]

obtained through Gaussian Elimination

One decoding scheme
(simple equation-solving)

Can decode using both encoded and un-encoded packets

Sliding Window Encoding:

Multi-hop Re-encoding:
If TCP is faster, it is by a small amount (usually less than 1s). In contrast, CTCP download times are substantially lower (>30s in 5% of the cases).

- 1354 data pairs
Recoding

64 packets

40%  40%

80%  60%  60%

D

No need for signalling!

impact of recoding

impact of field size

prob. D has not received all 64 after X trans.

F=256 R=0 S=0  F=2 R=0 S=0  F=256 R=1 S=0  F=2 R=1 S=0
KODO

• Fast track to utilize network coding for research and industry by flexible, tested, maintained & high performance solution.
• Hardware and multi core support
• Library source code fully available. Licenses free for research/educational but paid if commercial interest exist.
• C++ but bindings for C, Java and Python
KODO: Sparse Network Codes

- More dense
- ≈ 20 MB/s
- ≈ 300 MB/s
- ≈ 33 MB/s
- ≈ 0.4 MB/s

One or two orders of magnitude in the coding speed by sparsity.
KODO: FULCRUM

Fluid allocation of complexity
NC Application Fields

- Channel Bundling (see IETF Multi Path TCP)
- Peer-to-Peer (see IETF WebRTC)
- Point-to-Point with delay constraints (TCP)
- Distributed Storage and Edge Caching
- Device-to-Device Communication (LTE-A)
- Reliable Multicast (NORM)
- Wireless Mesh (LTE, WiFi, IoT, M2M)
Coded Cloud Storage Demonstration
Coding as a Measure Content of Protection
Results for Distributed Clouds

Heterogeneity (4 clouds)
• Clouds behave differently
• Real measurements

Speed-Up (5 clouds)
• RLNC optimally uses real-time available resources

Important for information retrieval!
G = 20
Q = 4

C = 10
P ≤ N - K = 5
K = 3

Rounds
Cloud Migration Results

No Coding

RS Coding

Network Coding

storage

traffic

reliability

storage

traffic

reliability

storage

traffic

reliability
Cloud Migration Results

No Coding

RS Coding

Network Coding

reliability

storage

traffic
AAU SDN Testbed
Conclusion

• Future networks have to cope with higher dynamics and are less planable
• Storage is not in the backbone anymore, but in the network, and at the edges
• Network coding is a viable solution to address the described problems in networks and storage with the same CODES.