UNIVERSITÄT OSNABRÜCK

November 2019

Bridging the gap:

Challenges of deploying Network Coding in the real world

Bertram Schütz

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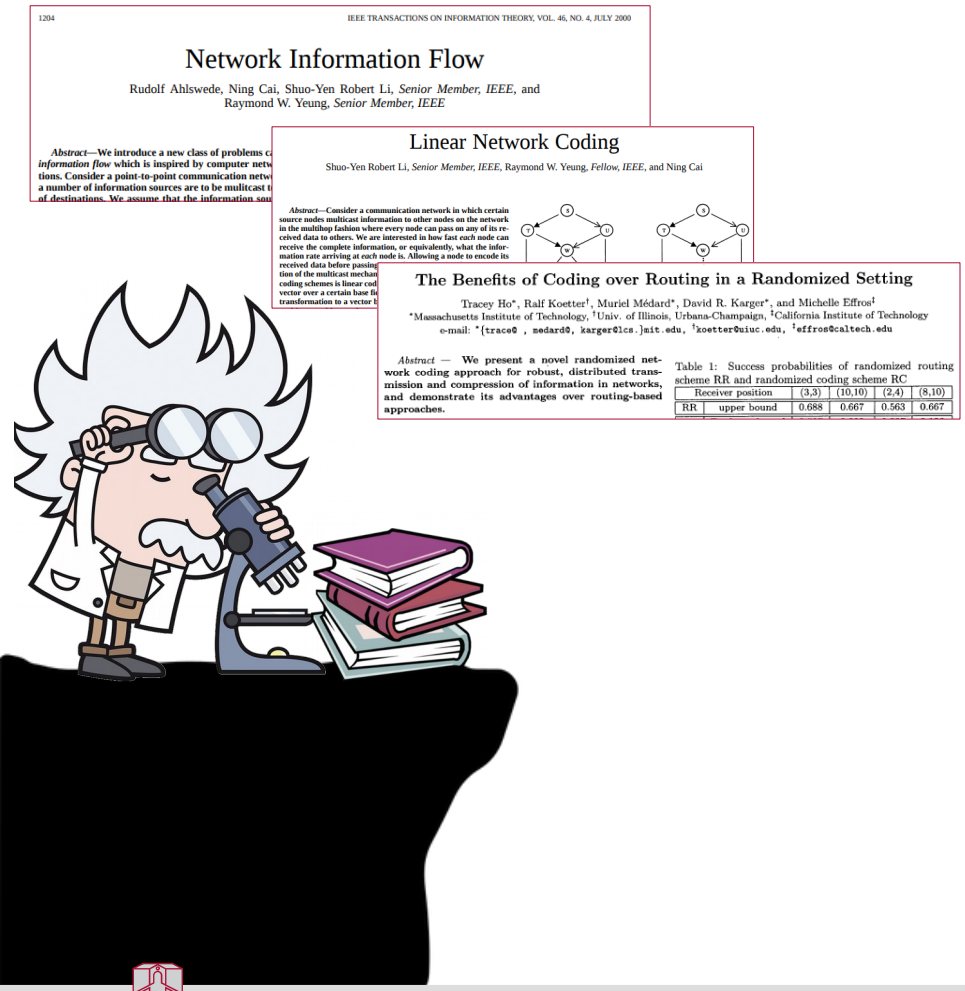

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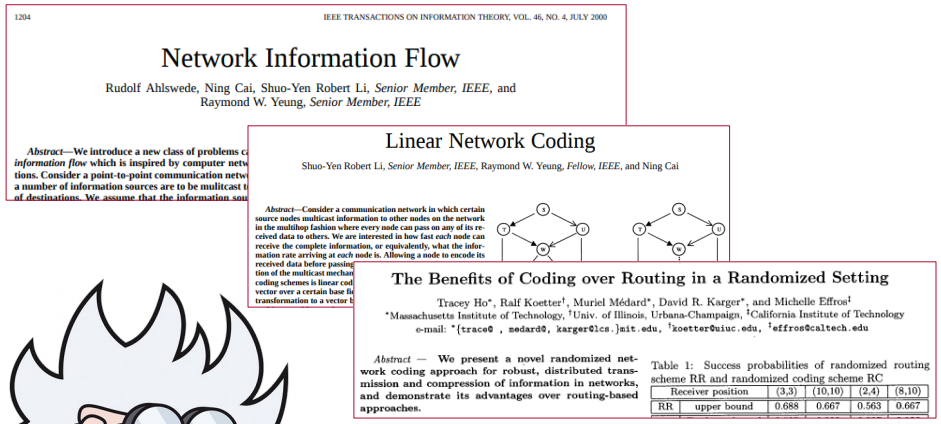


1204 IEEE TRANSACTIONS ON INFORMATION THEORY, VOL. 46, NO. 4, JULY 2000

Network Information Flow

Rudolf Ahlswede, Ning Cai, Shuo-Yen Robert Li, *Senior Member, IEEE*, and Raymond W. Yeung, *Senior Member, IEEE*

***Abstract*—We introduce a new class of problems c*
information flow which is inspired by computer netw
tions. Consider a point-to-point communication netw
a number of information sources are to be multicast t
of destinations. We assume that the information sou

Linear Network Coding

Shuo-Yen Robert Li, *Senior Member, IEEE*, Raymond W. Yeung, *Fellow, IEEE*, and Ning Cai

***Abstract*—Consider a communication network in which certain source nodes multicast information to other nodes on the network in the multihop fashion where every node can pass on any of its received data to others. We are interested in how fast *each* node can receive the complete information, or equivalently, what the information rate arriving at *each* node is. Allowing a node to encode its received data before passing**

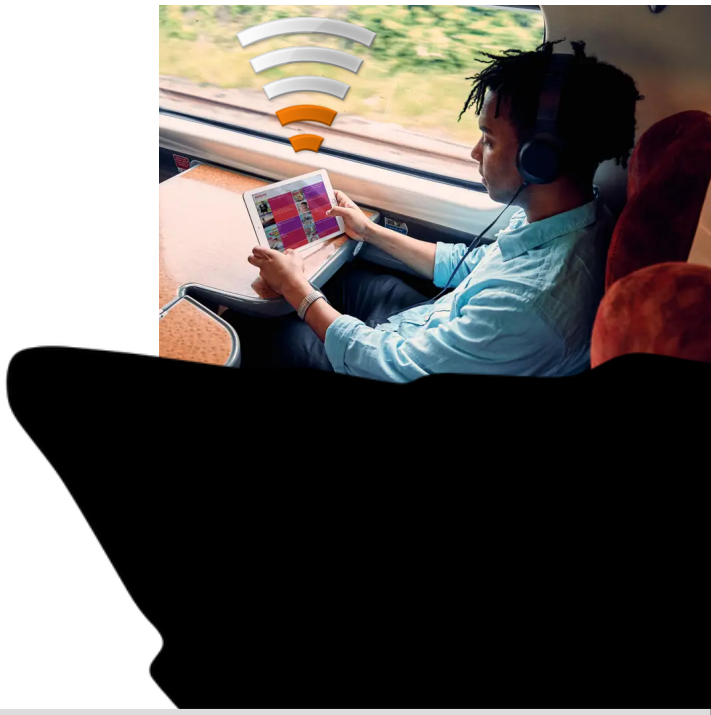
The Benefits of Coding over Routing in a Randomized Setting

Tracey Ho*, Ralf Koetter†, Muriel Médard*, David R. Karger*, and Michelle Effros‡
*Massachusetts Institute of Technology, †Univ. of Illinois, Urbana-Champaign, ‡California Institute of Technology
e-mail: *{trace@ , medard@, karger@lcs.}mit.edu, †koetter@uiuc.edu, ‡effros@caltech.edu

Abstract — **We present a novel randomized network coding approach for robust, distributed transmission and compression of information in networks, and demonstrate its advantages over routing-based approaches.**

Table 1: Success probabilities of randomized routing scheme RR and randomized coding scheme RC

Receiver position		(3,3)	(10,10)	(2,4)	(8,10)
RR	upper bound	0.688	0.667	0.563	0.667



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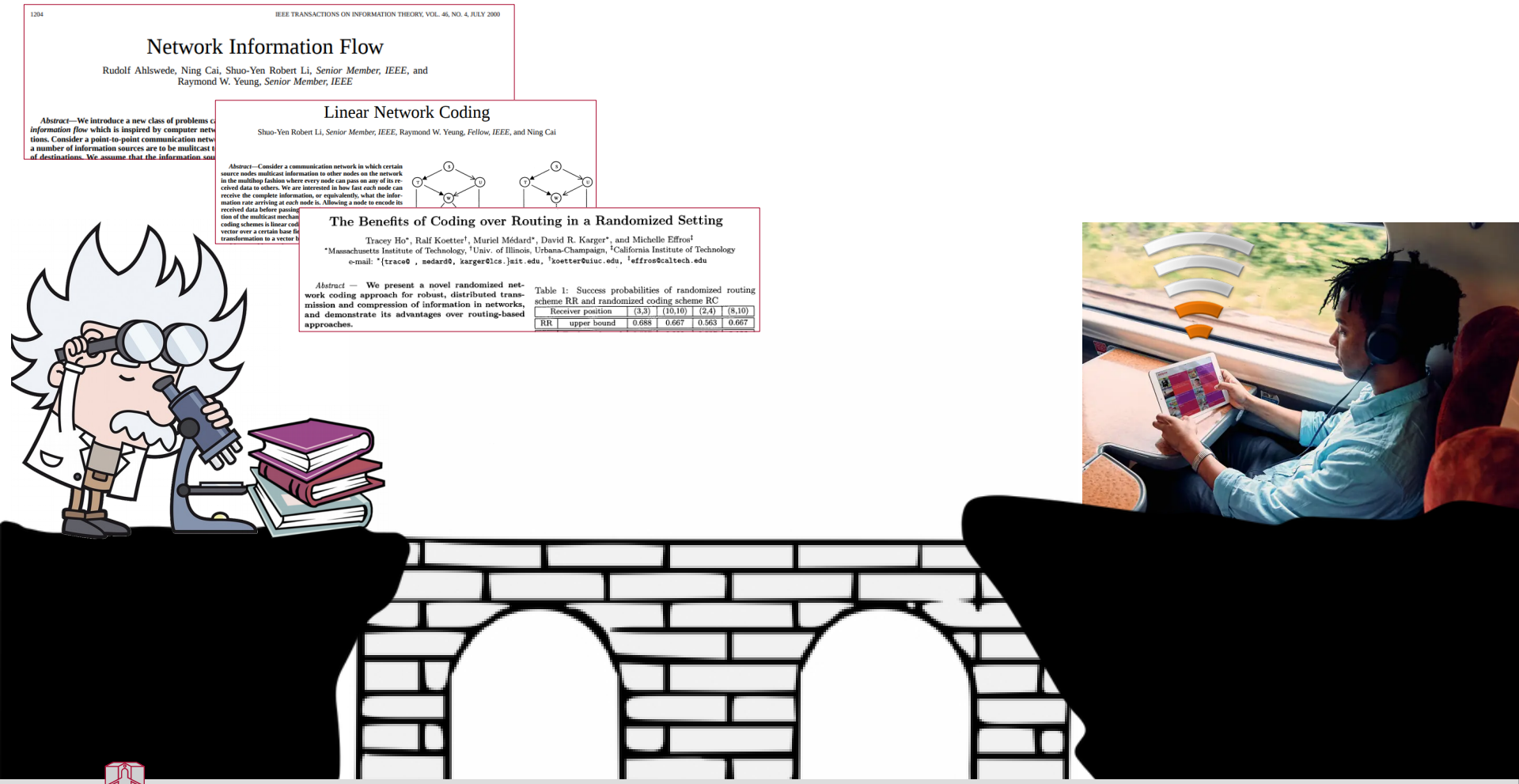

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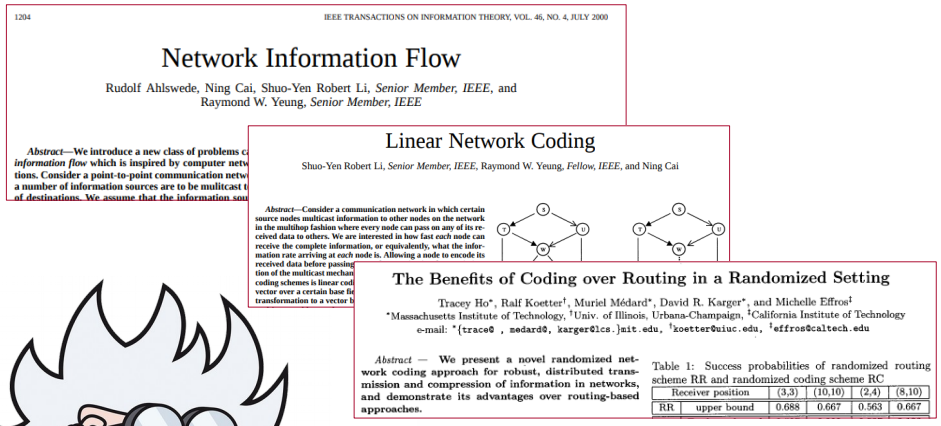
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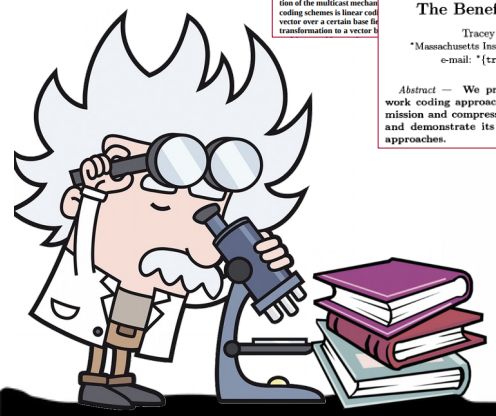


OSI Stack Integration

Codec Parameterization

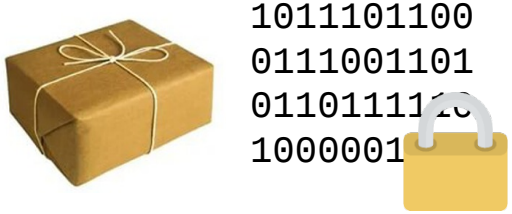
Padding Overhead

Network Coding Basics

Concept based in Information Theory:

Domain Shift of Data

Physical Domain



Immutable Bits

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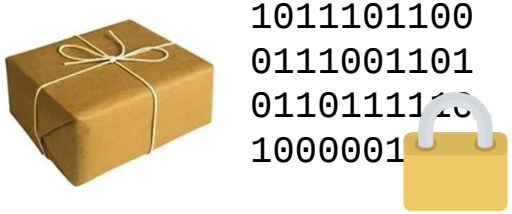

Immutable Bits

Algebraic Domain

$11001010 = 1x^7+1x^6+0x^5+0x^5+1x^3+0x^2+1x+0$

Equations over Finite Field
e.g. $x \in GF(2^8) \triangleq$ 1 Byte

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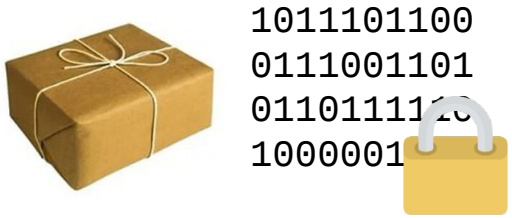

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Immutable Bits → Equations over Finite Field

e.g. $x \in GF(2^8) \triangleq 1$ Byte

Allow **calculations** on packets

Network Coding Basics

Inter-stream
Scheduling Alternative

Intra-stream
Forward Error Correction (FEC)

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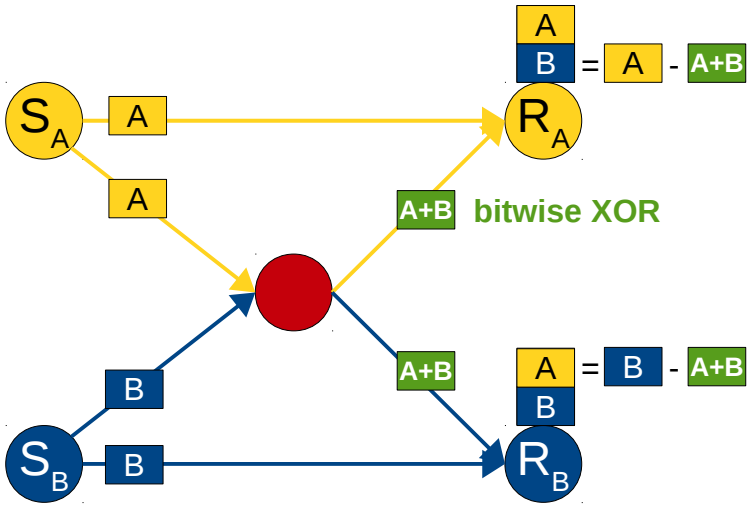
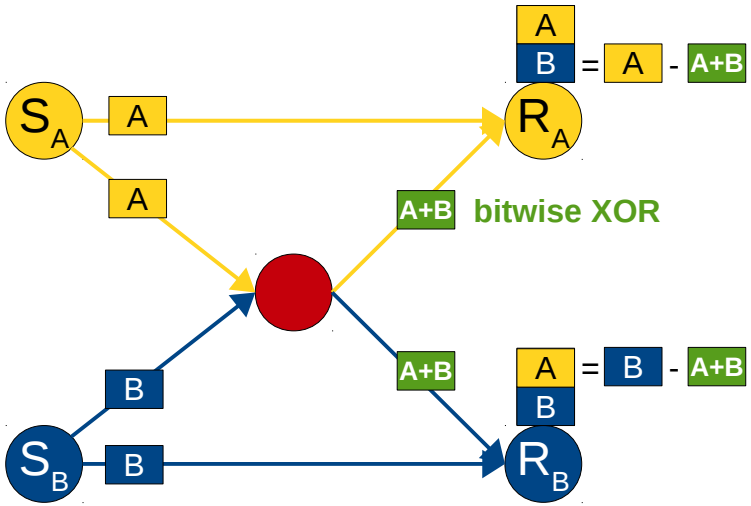


Butterfly Network

Multi-Commodity Flow
for Multicast

Network Coding Basics

Inter-stream
Scheduling Alternative



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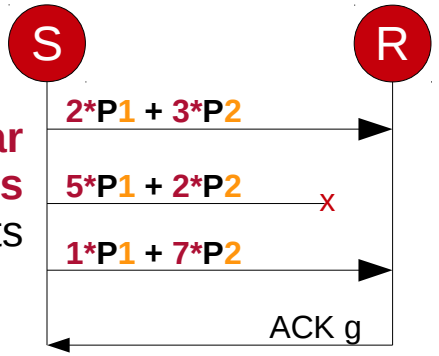
Forward Error Correction (FEC)

Send **linear combinations** of packets



- Tradtional ARQ:
  each of the g original packets needed
- FEC:
- **any g** received packets sufficient

  → Less Feedback
  → Overcome Packet Loss

Network Coding Basics

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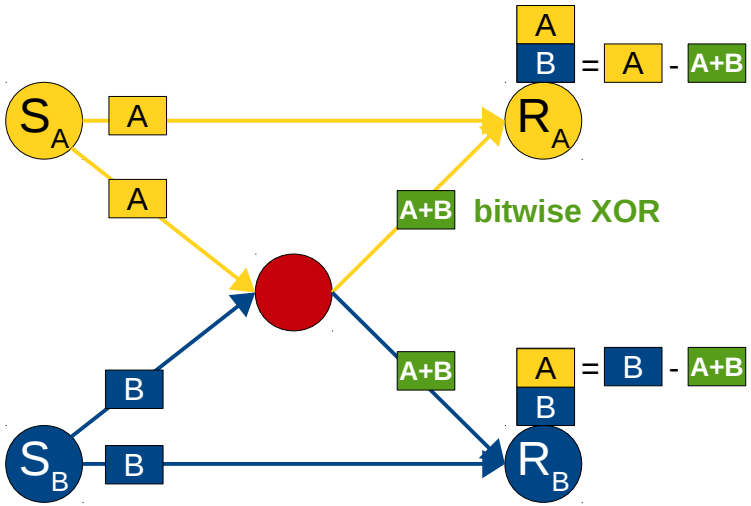

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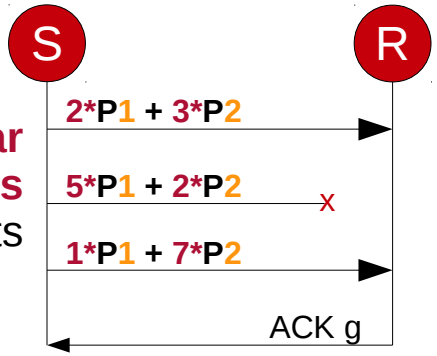

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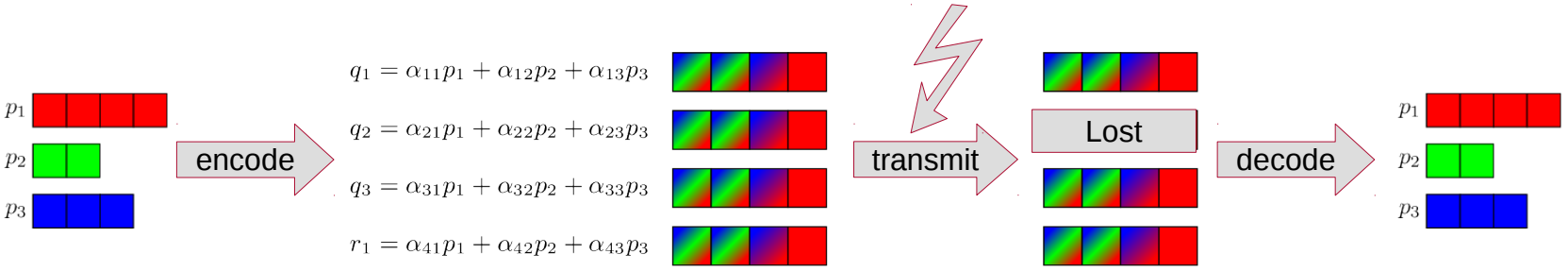

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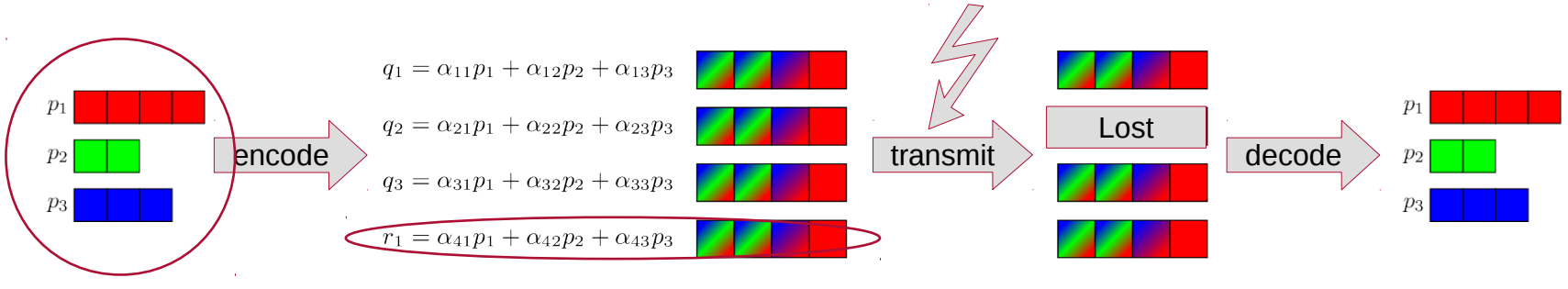
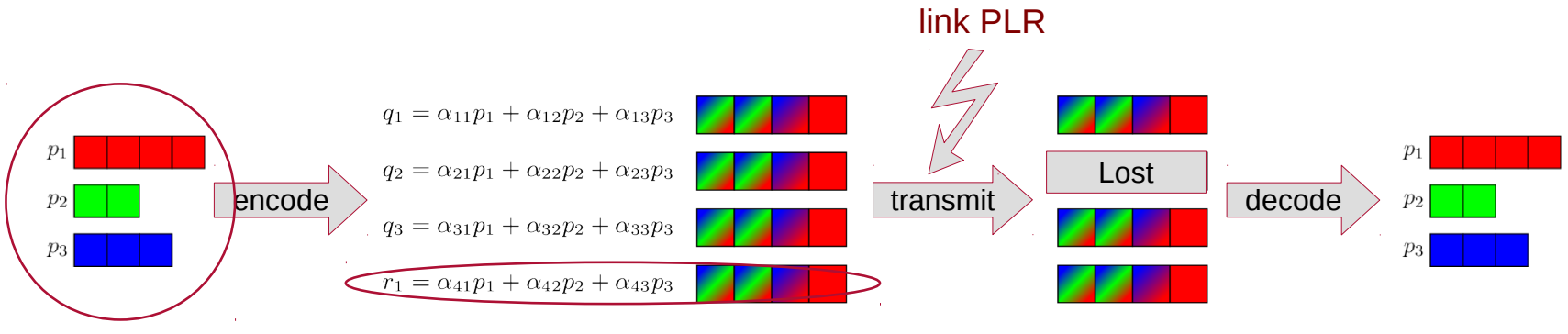


generation size g
(here 3)

redundancy r
(here 1/3 = 0.33)

Codec Parameterization
RLNC (g,r)

Intra-stream
Forward Error Correction (FEC)



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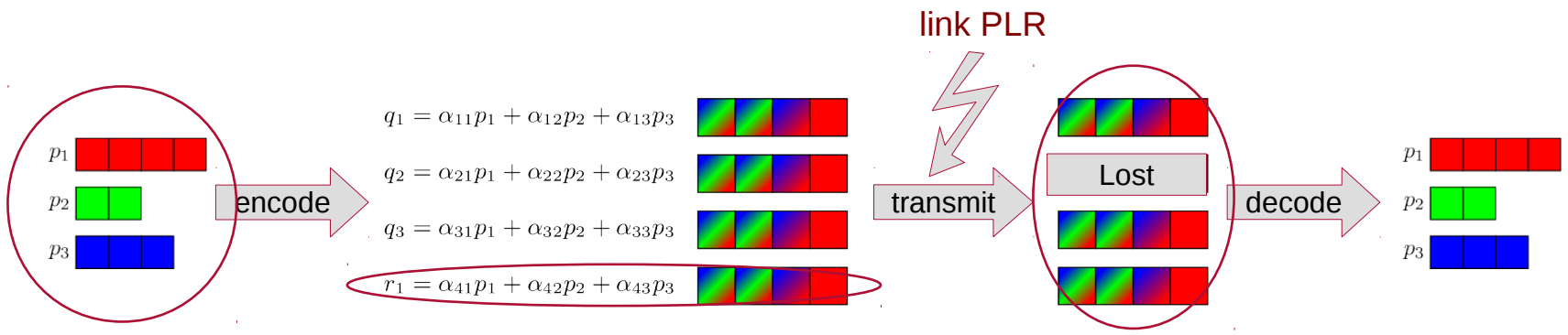

generation size g
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decoding condition:
rank ≥ g
(here 3 ≥ 3)

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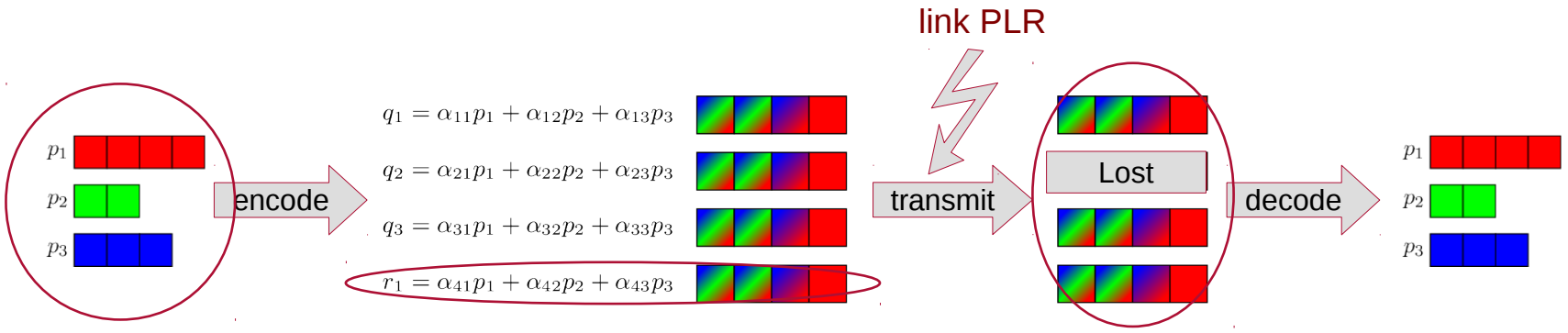

generation size g
(here 3)

redundancy r
(here 1/3 = 0.33)

decoding condition:
rank ≥ g
(here 3 ≥ 3)

(packets linear independent
with high probability)

Codec Parameterization
RLNC (g,r)

Example: H264 video streaming over lossy link

PLR 5% (Bernoulli)

Uncoded

Systematic RLNC
g=8, r=0.25

Systematic RLNC
g=8, r=0.50

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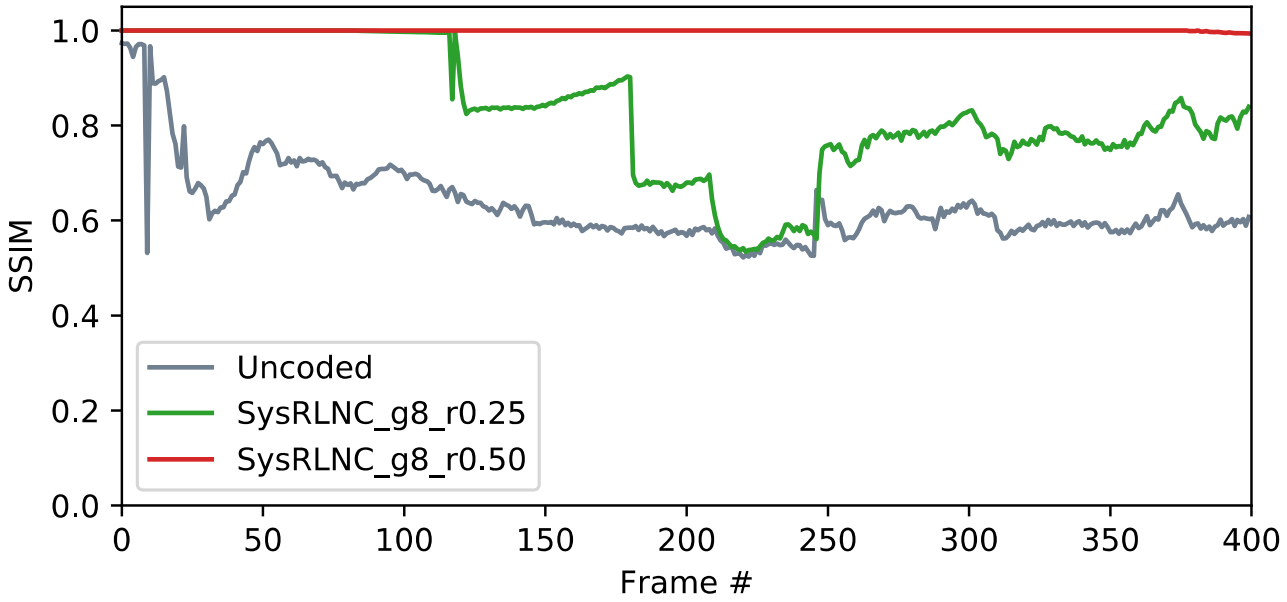
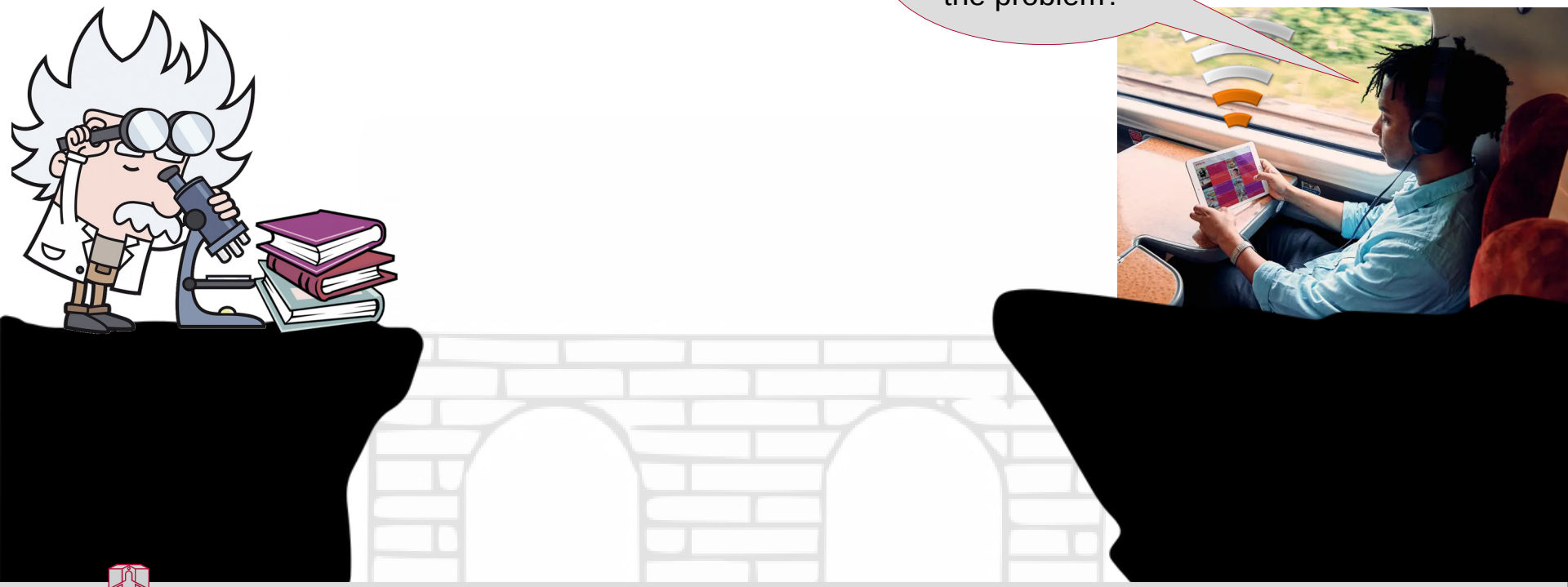
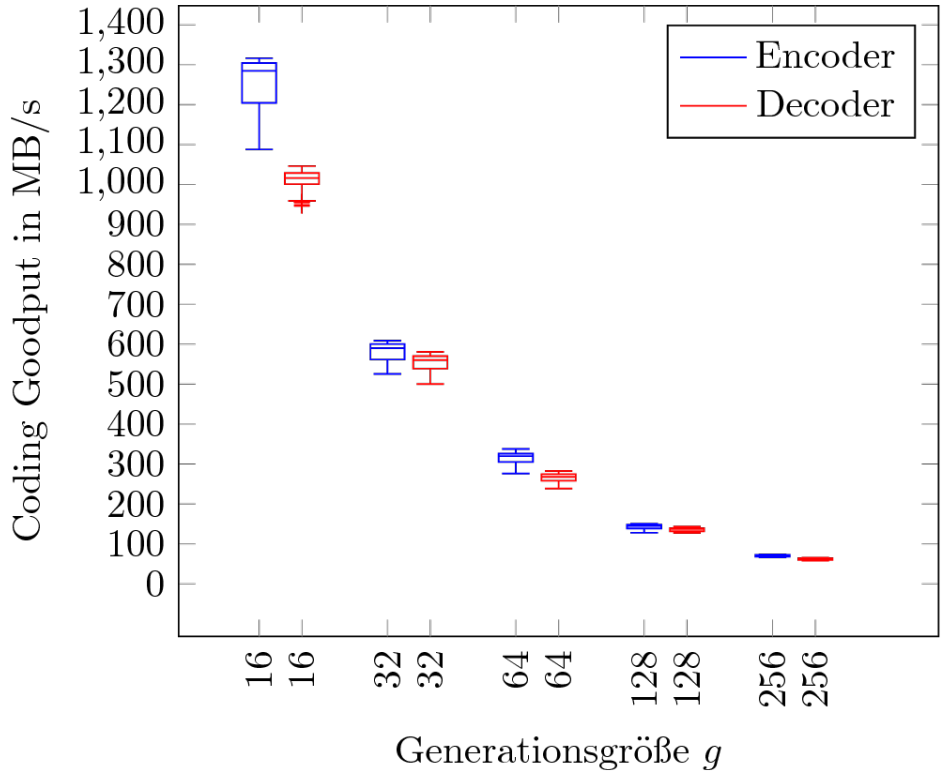



So …
Where is
the problem?

Coding Throughput & Processing Power Bottleneck?

Kodo Systematic RLNC Benchmark
Nuvo-5006E-PoE Router (i7-6700TE @ 2.4GHz)



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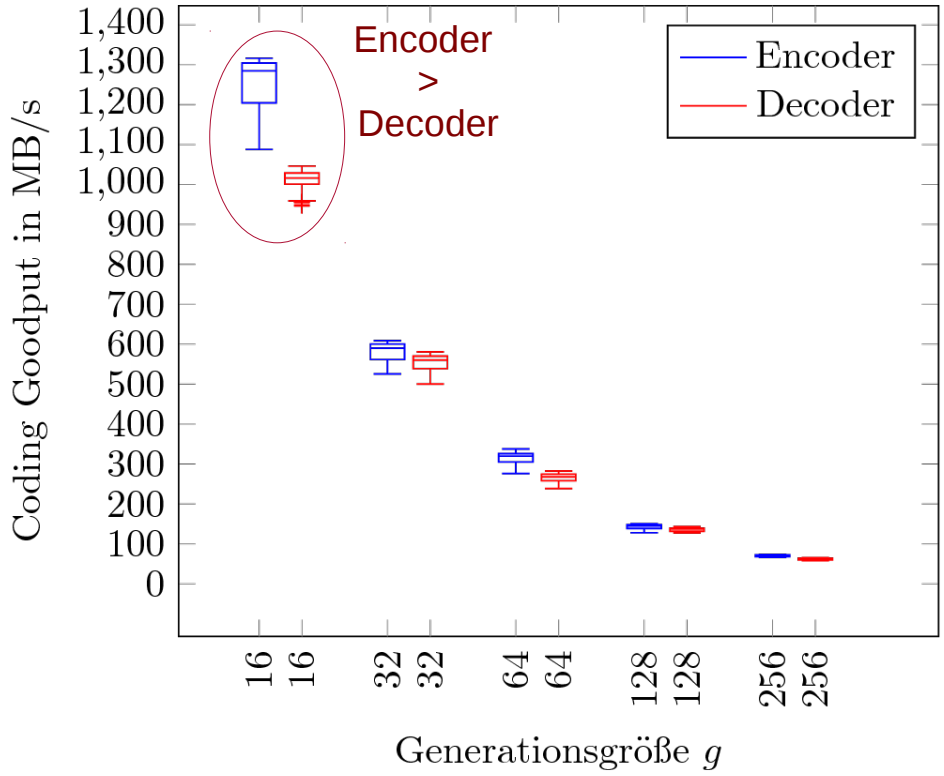

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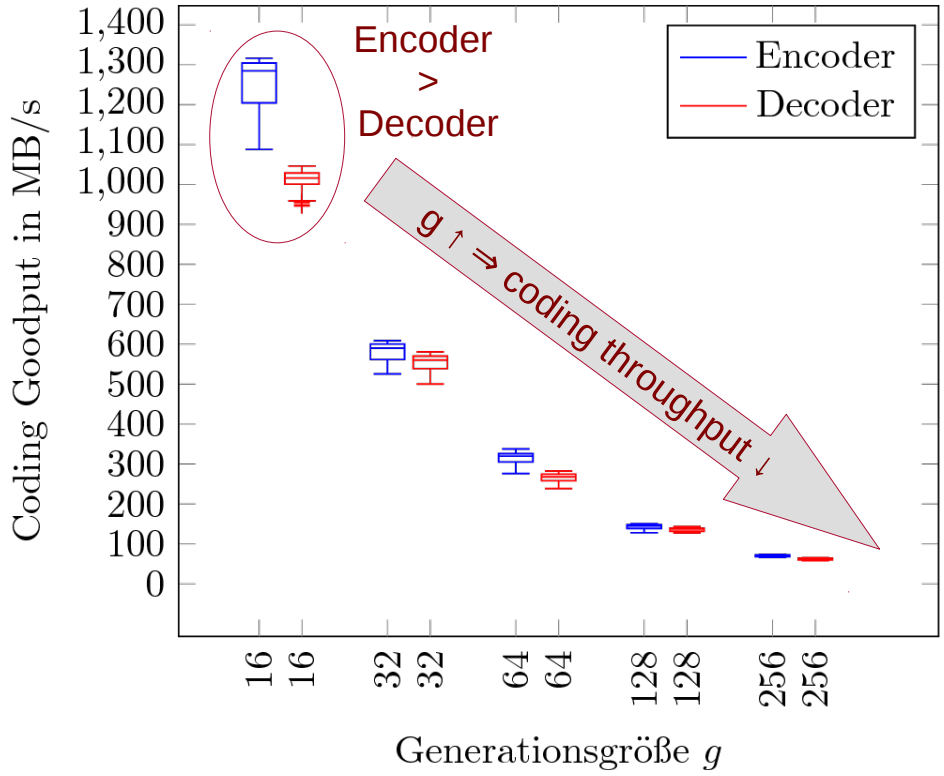

Coding Throughput & Processing Power Bottleneck?

coding throughput is not the main problem

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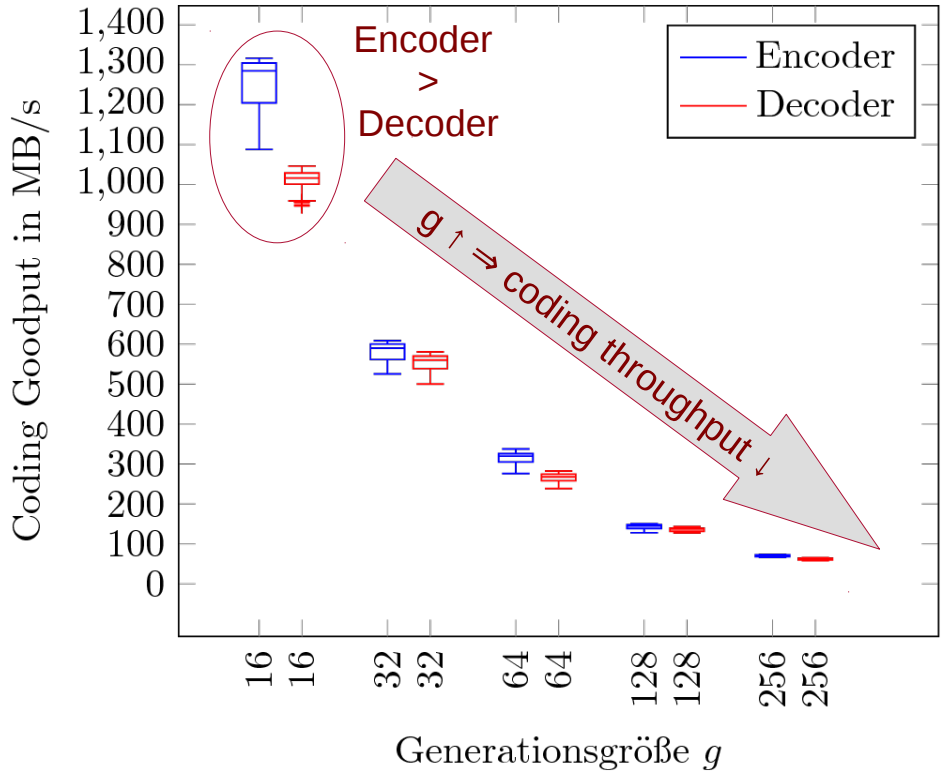

The main challenge:
Integration & Compatibility

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[spacelink.us]

Your everyday Wi-Fi devices
(IEEE 802.11 Standard):

- Smartphones
- Tablets
- Computers

[nasa.gov]

Specific devices / networks:

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- Wireless Sensor Networks

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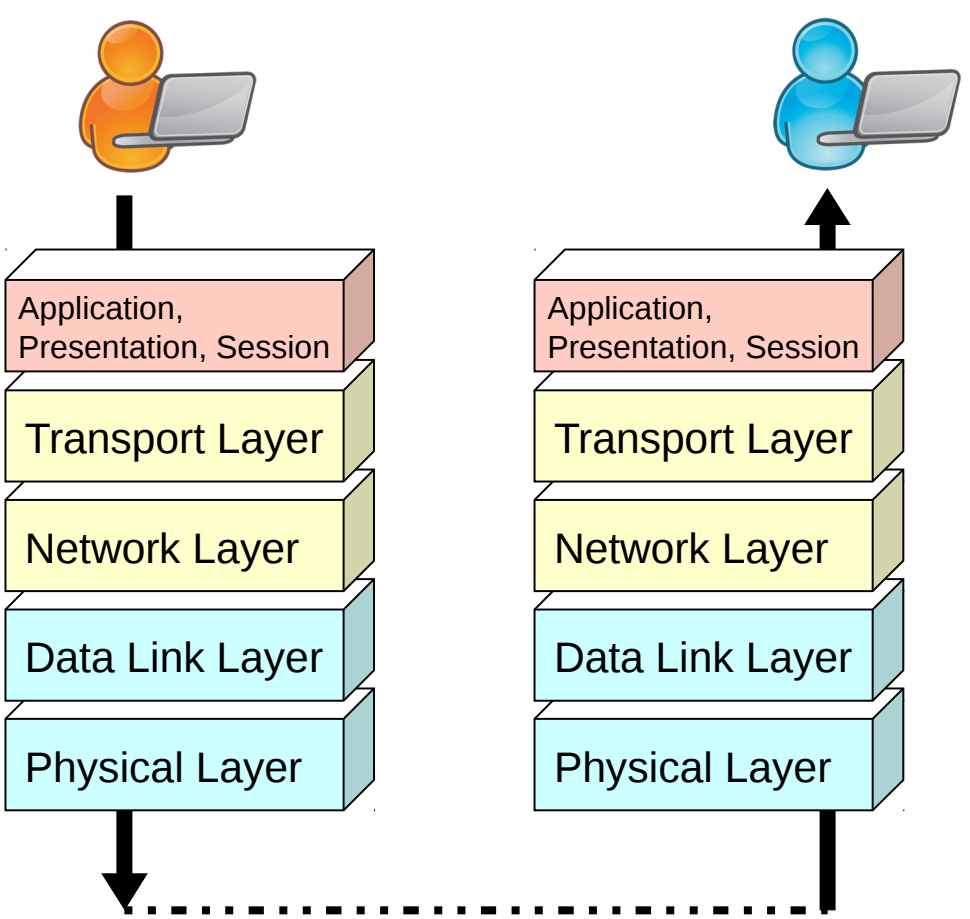
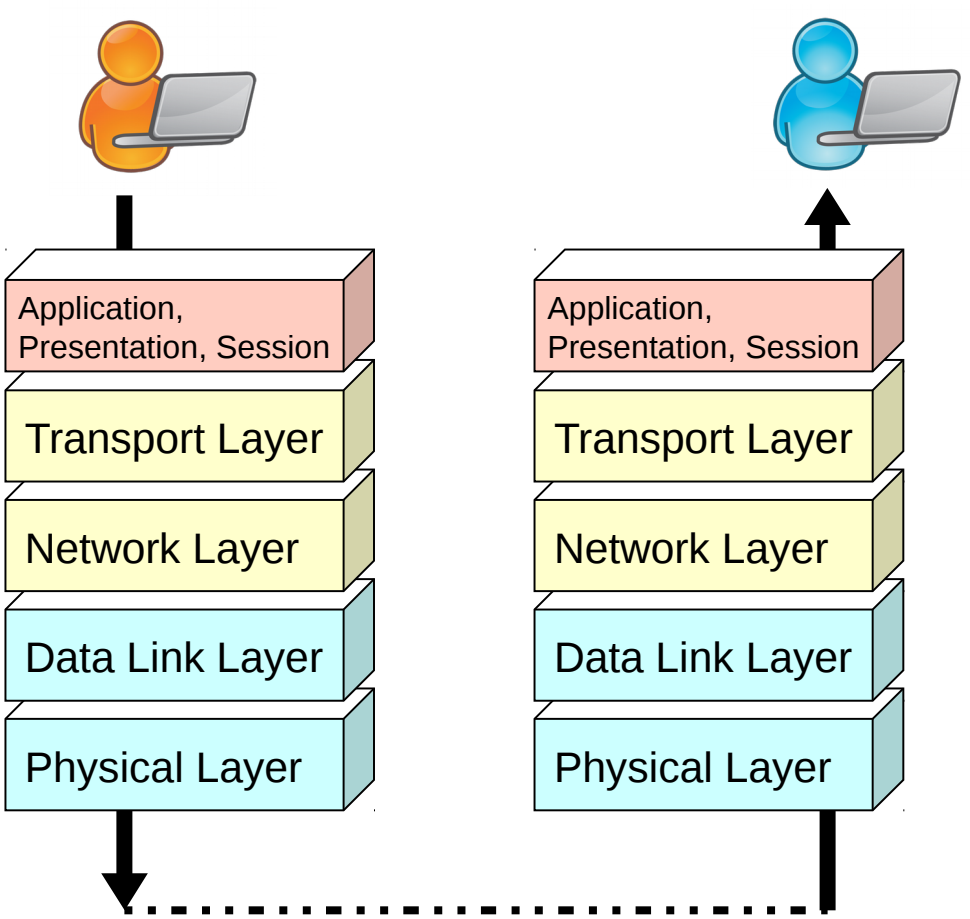
OSI Stack Restrictions



NC Integration:
CRC Error Detection



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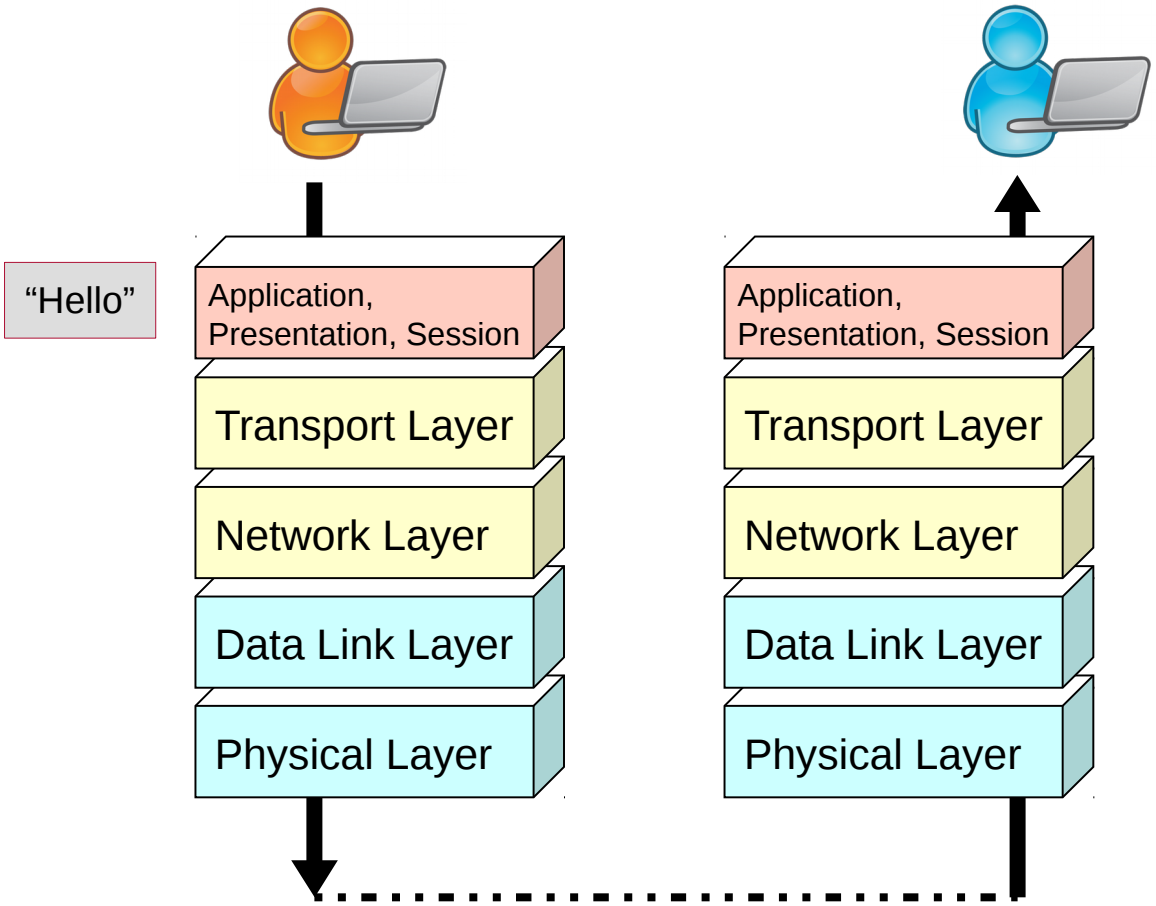

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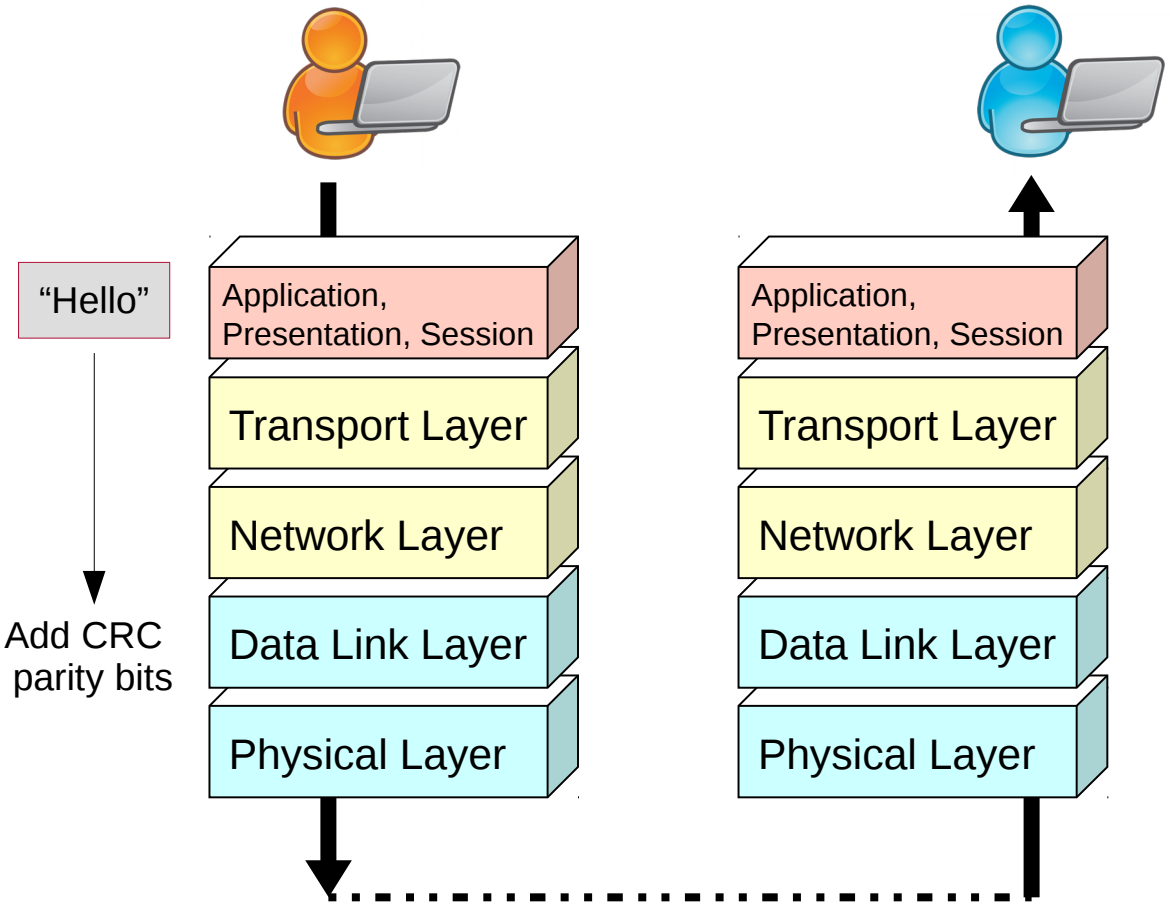

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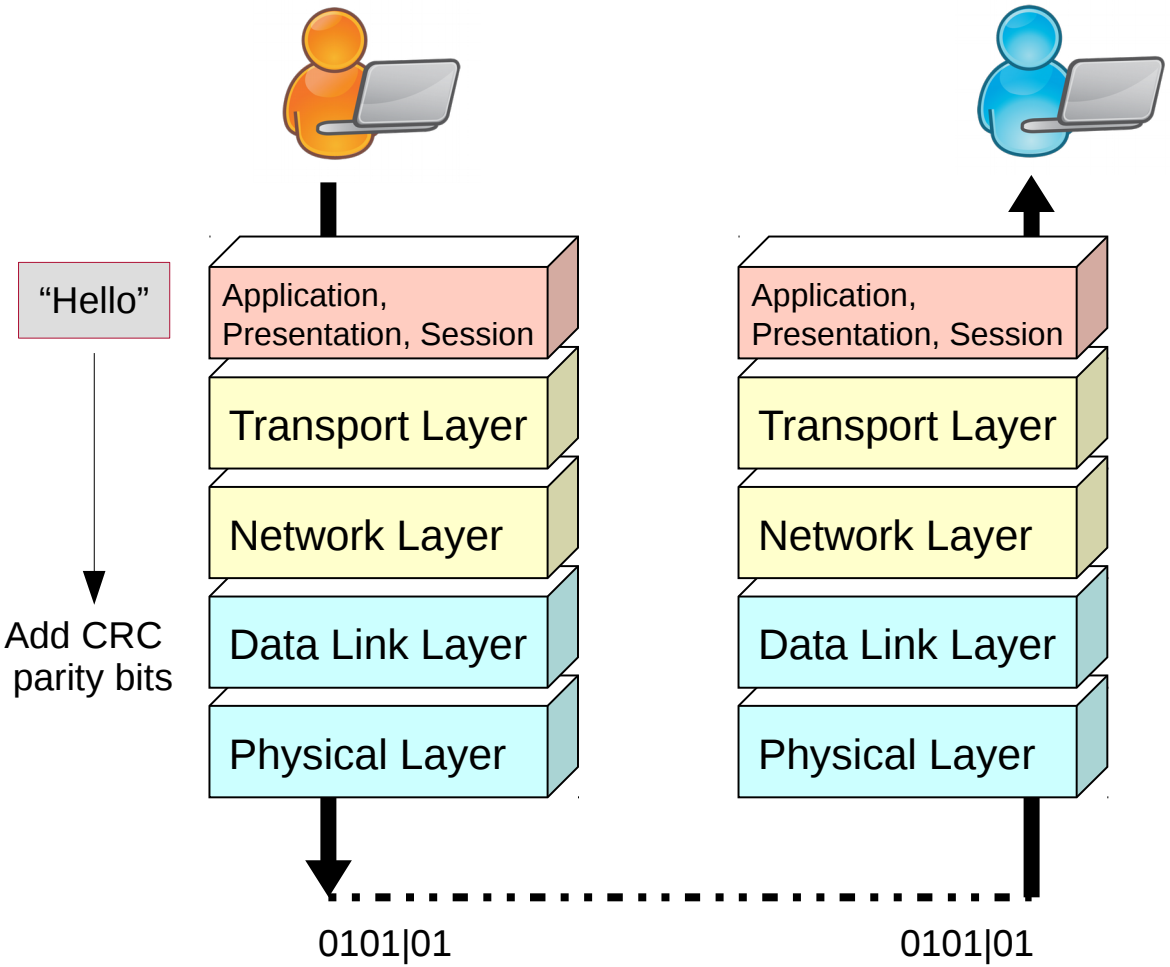

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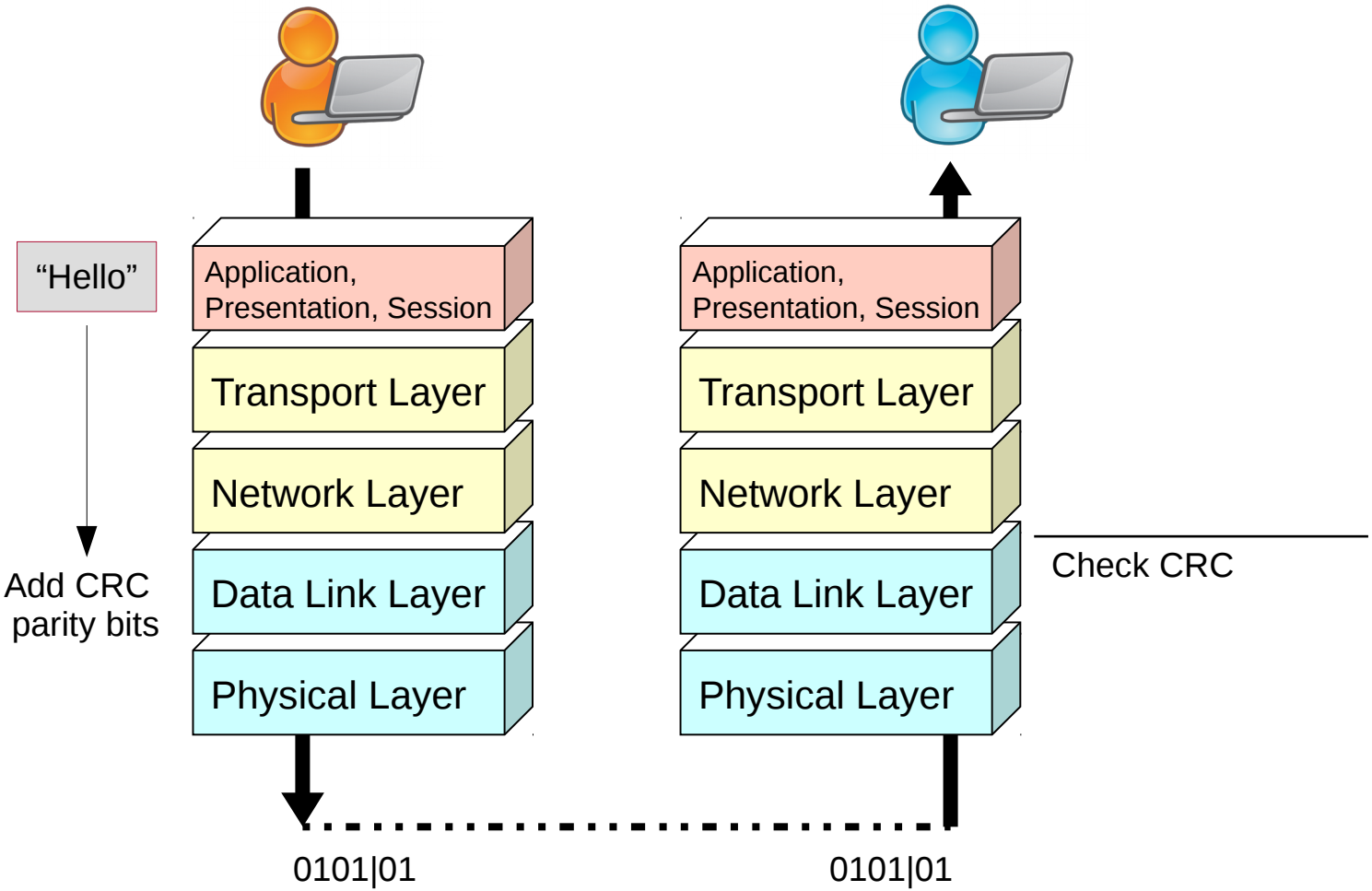

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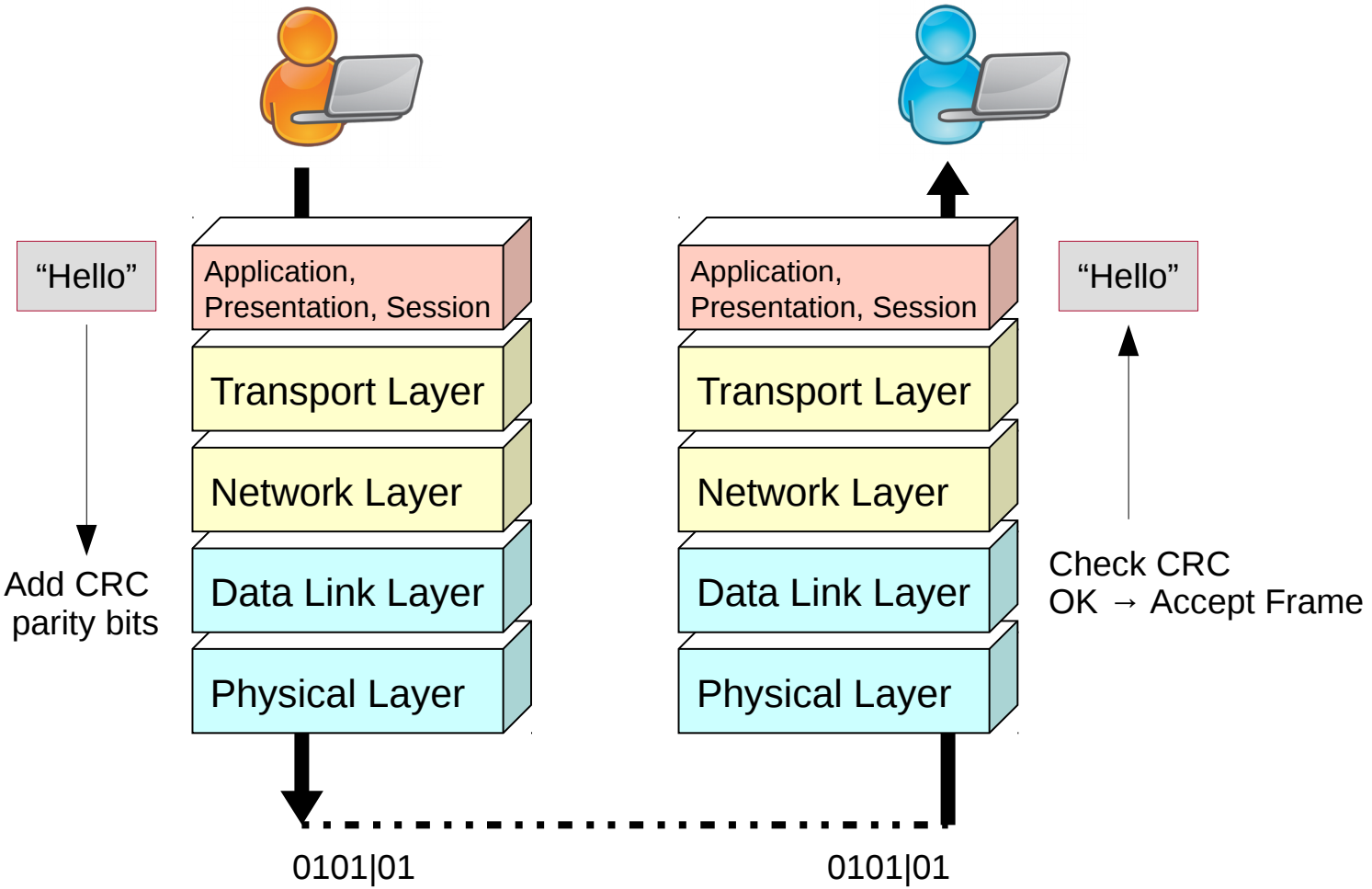

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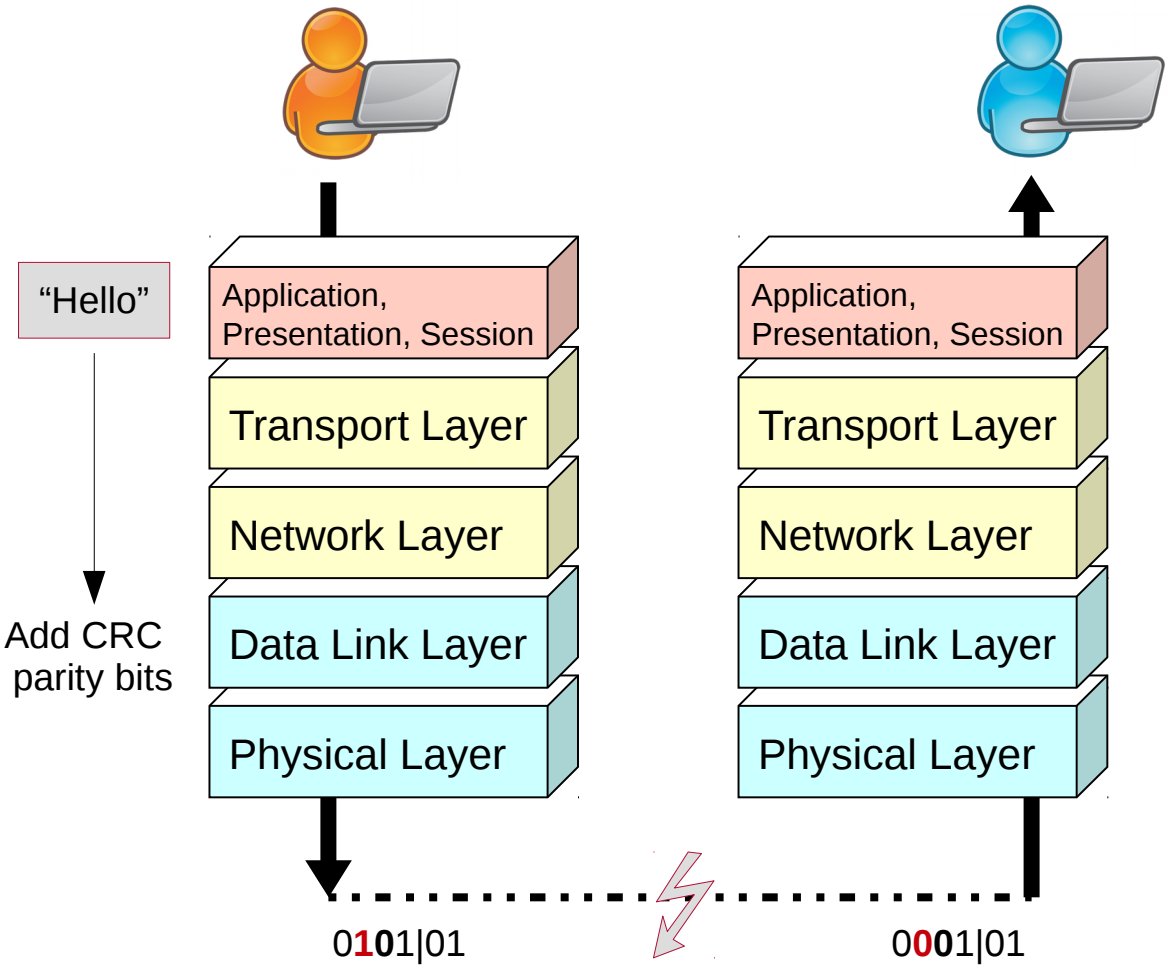

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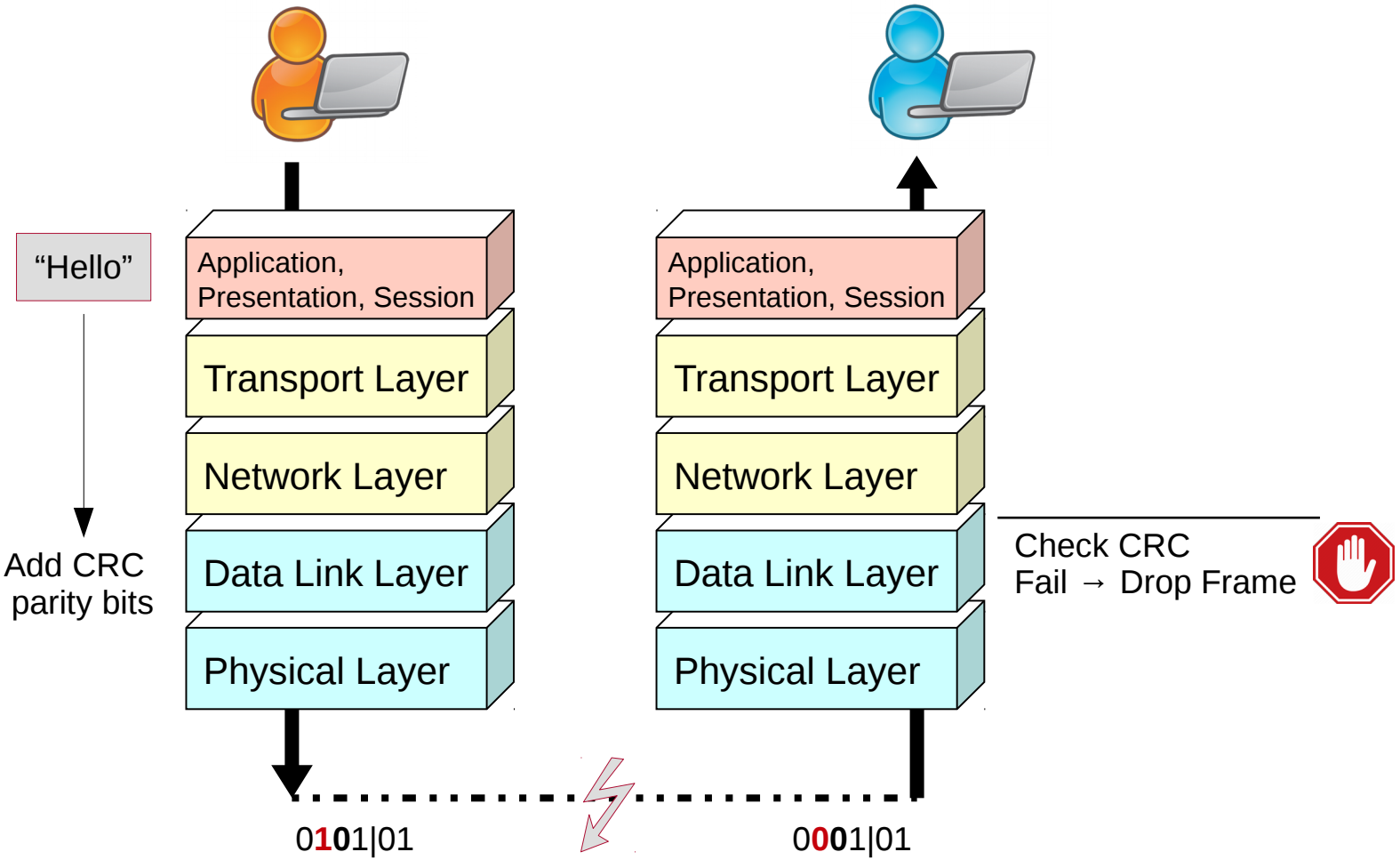

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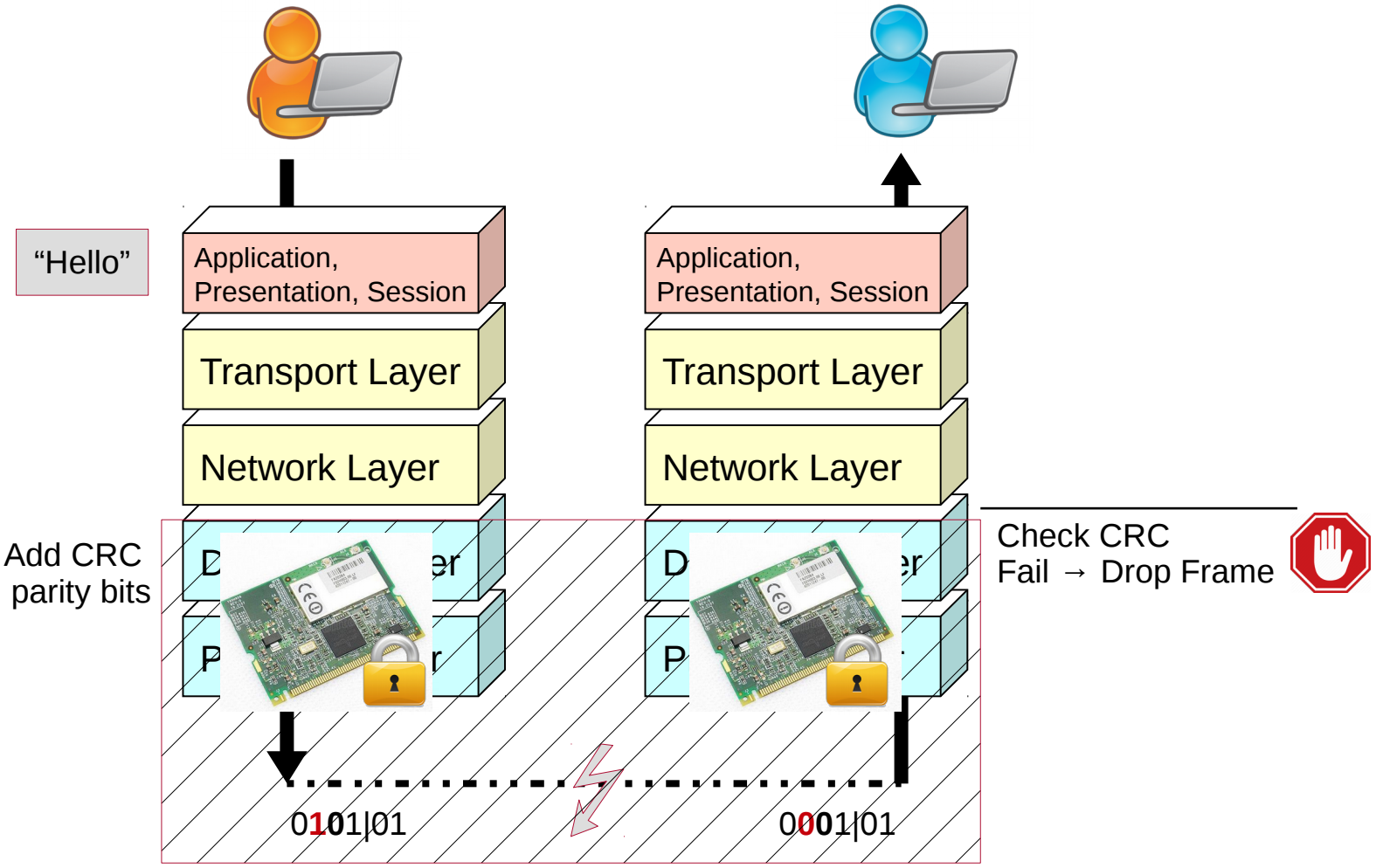

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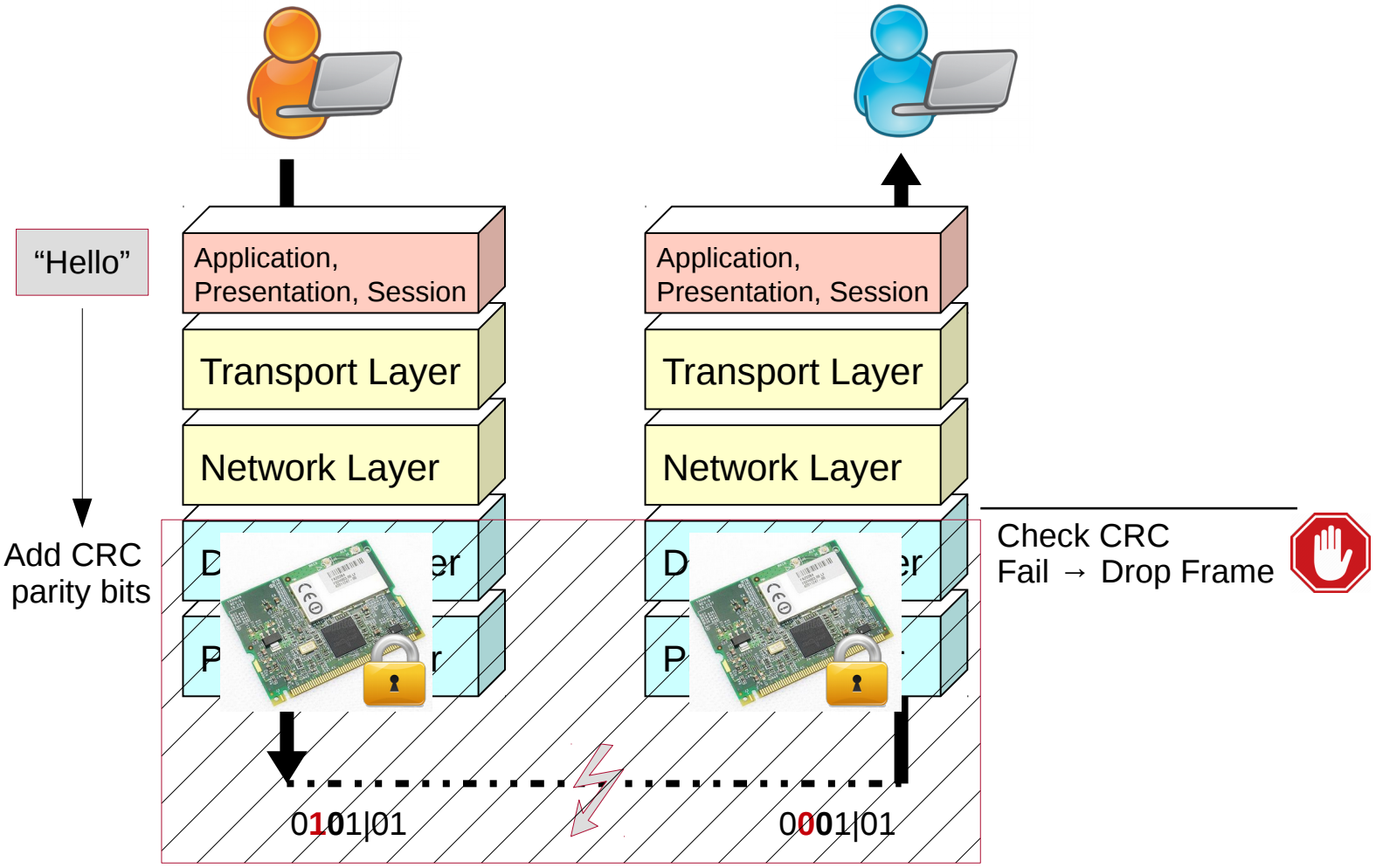
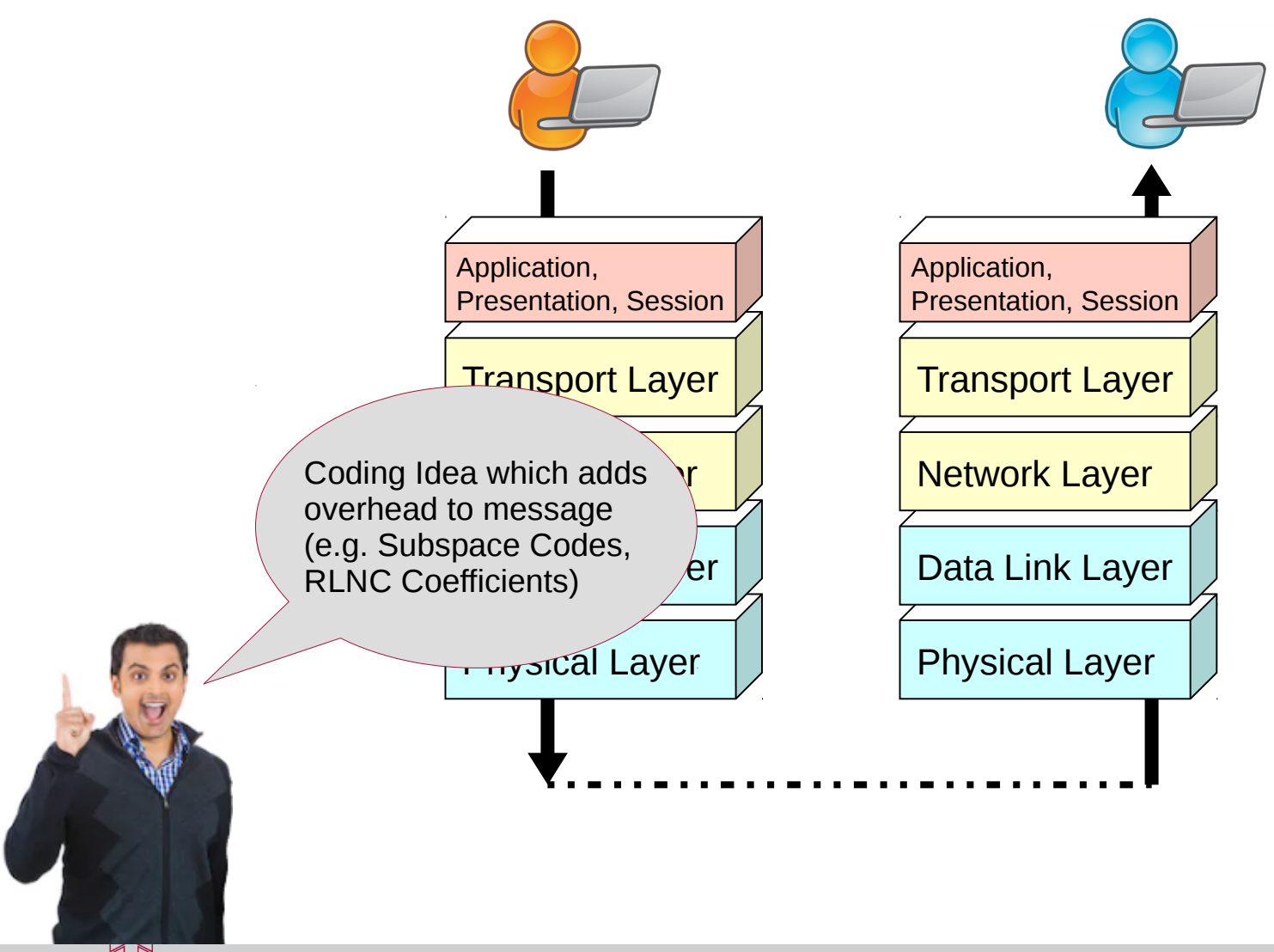


NC Integration:
Maximum Transmission Unit (MTU) & IP Fragmentation



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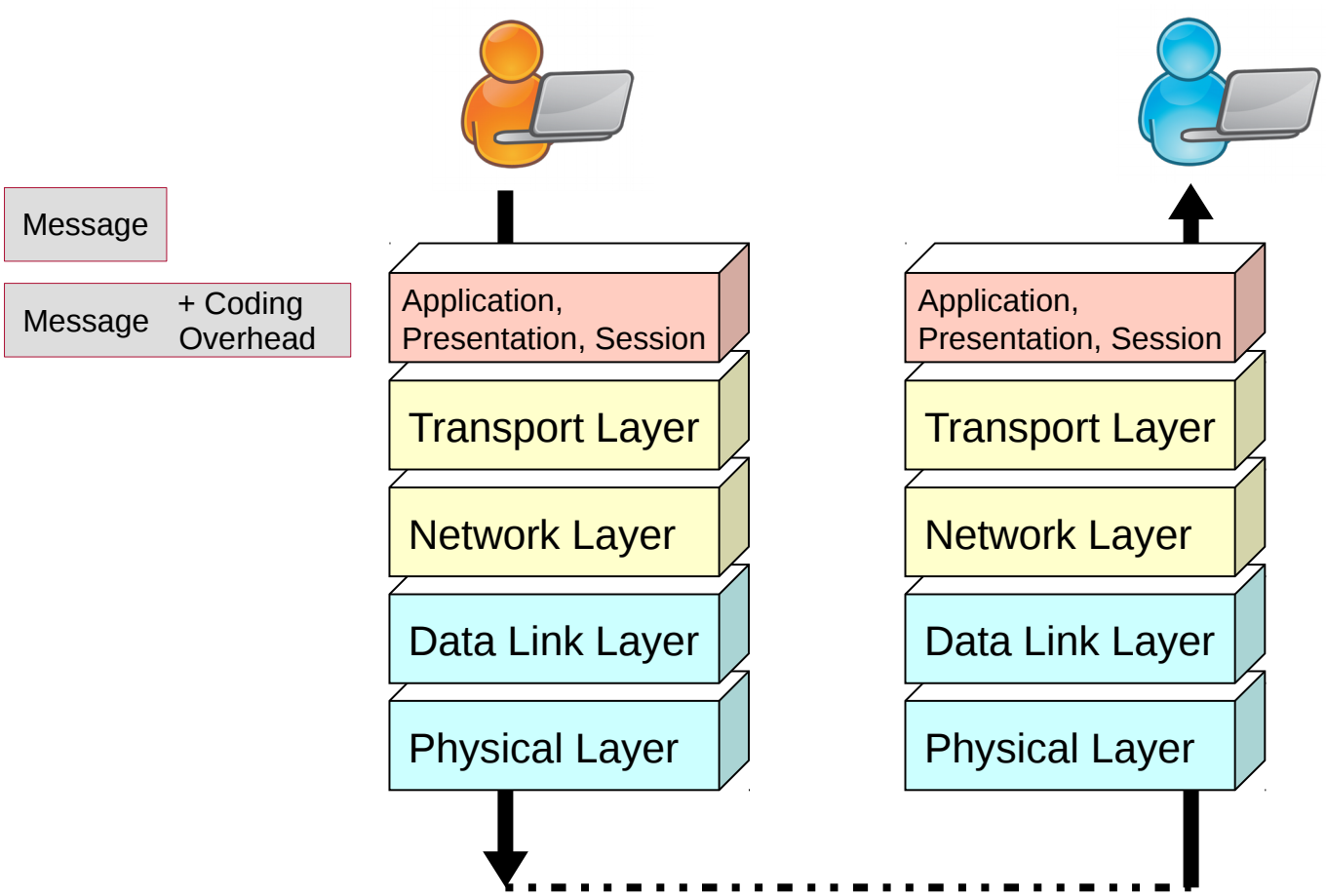

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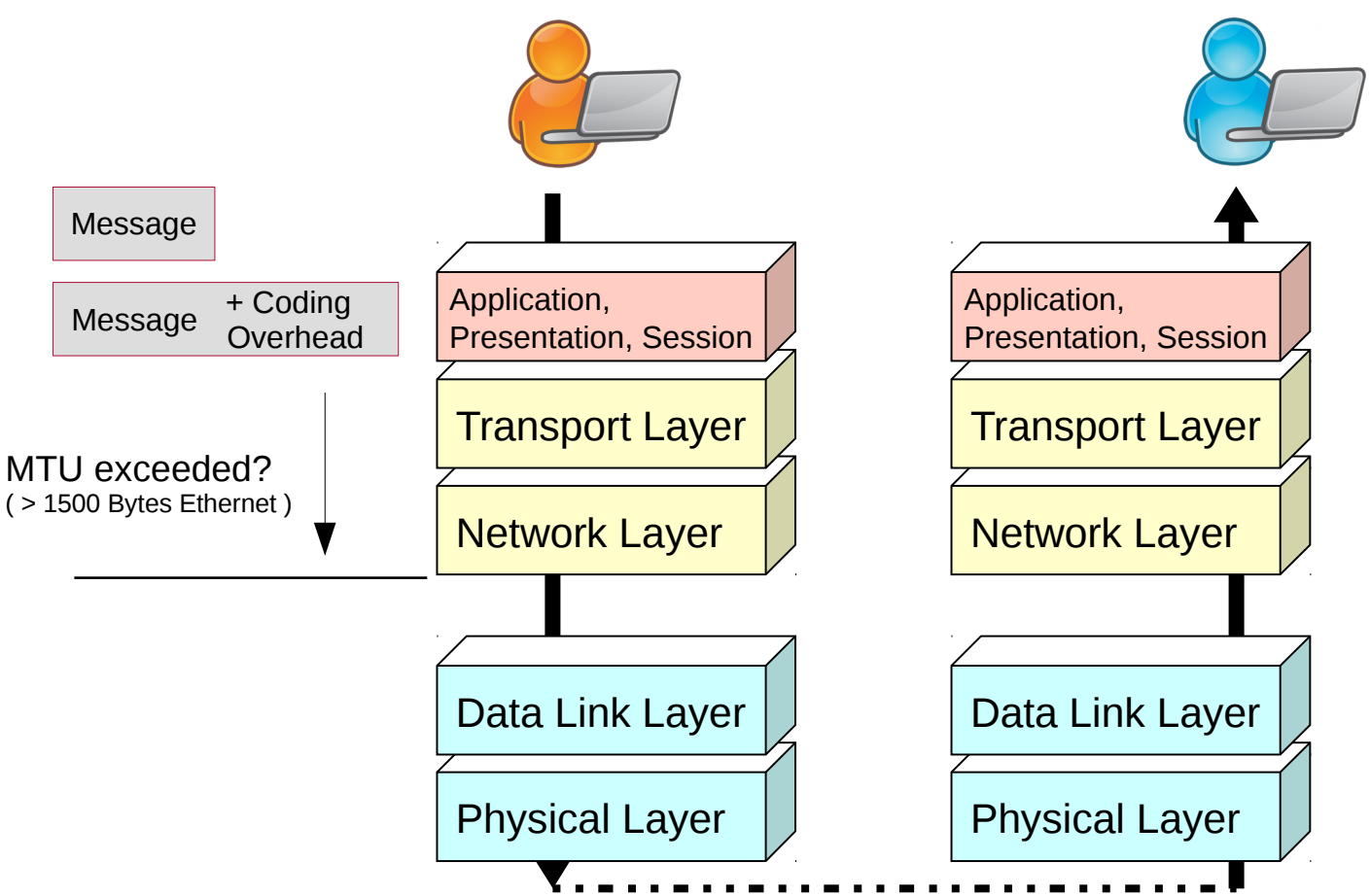

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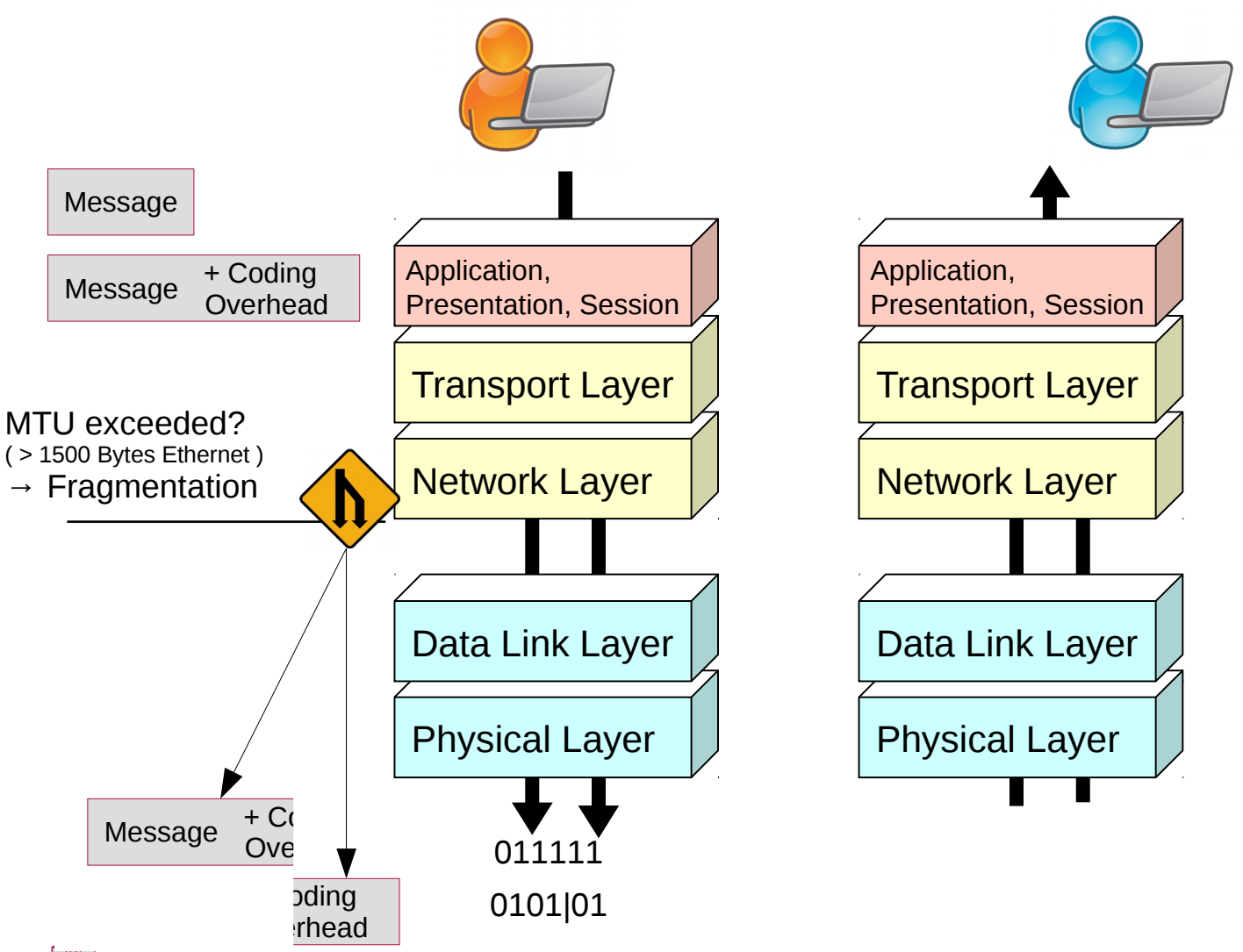

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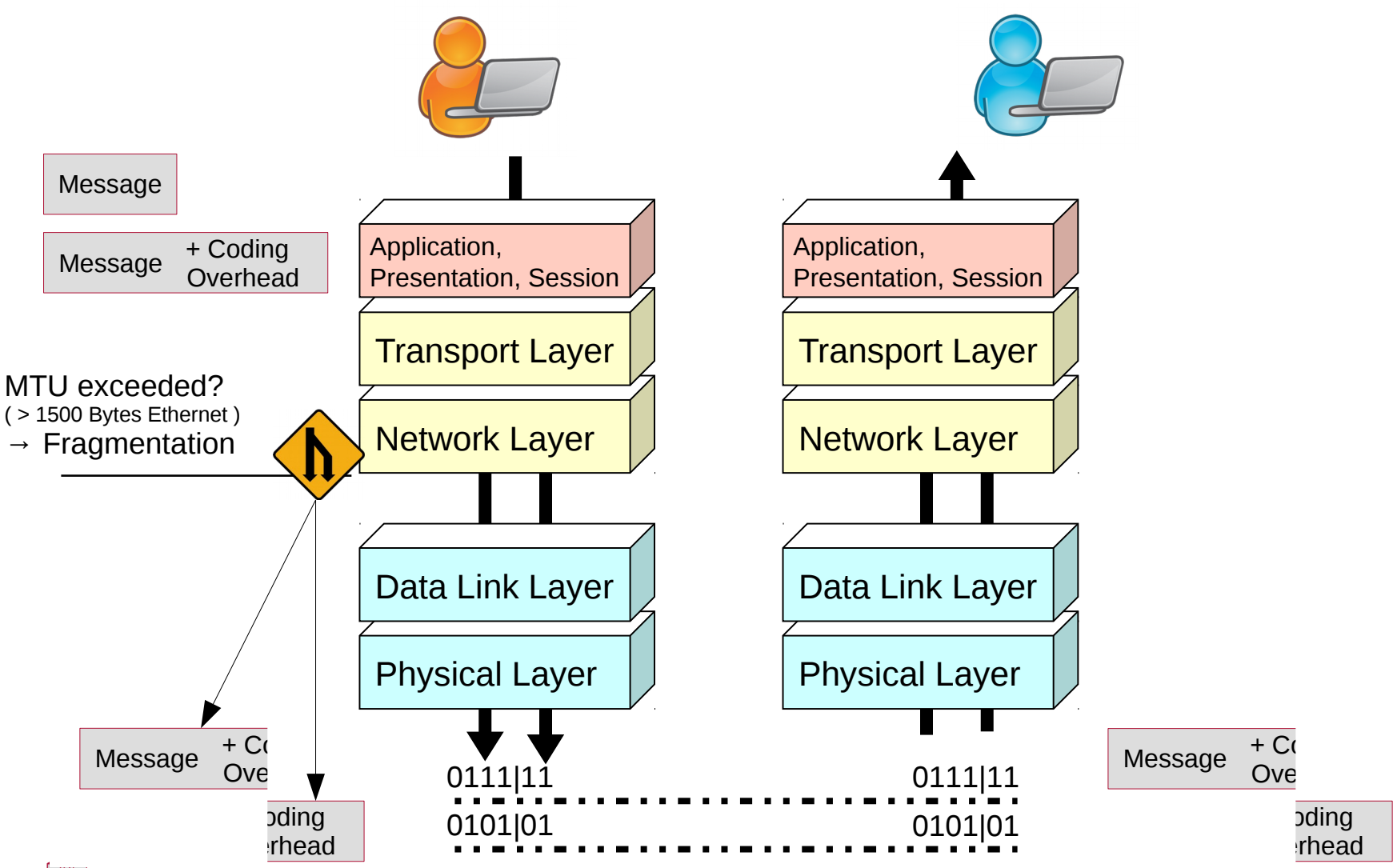

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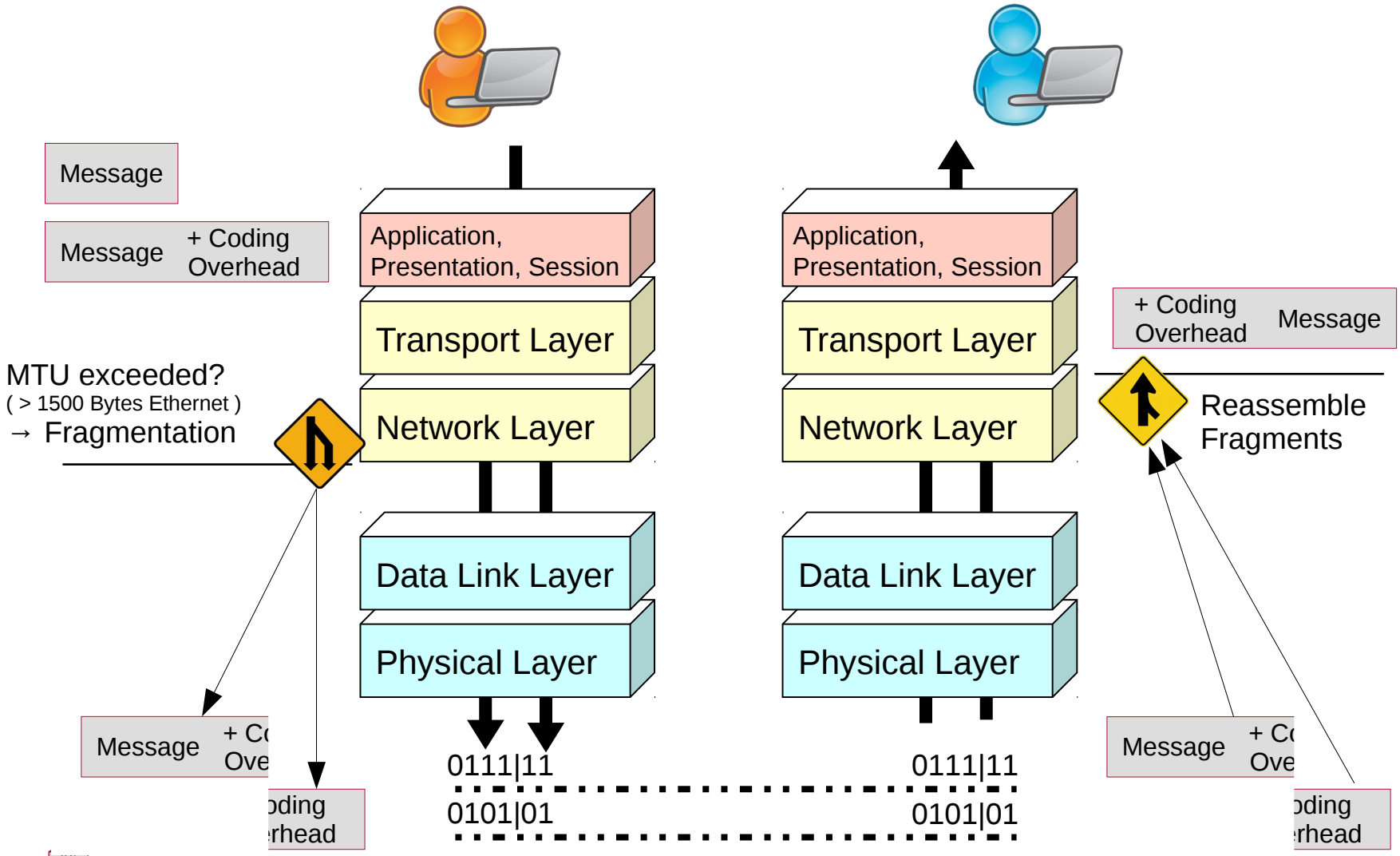

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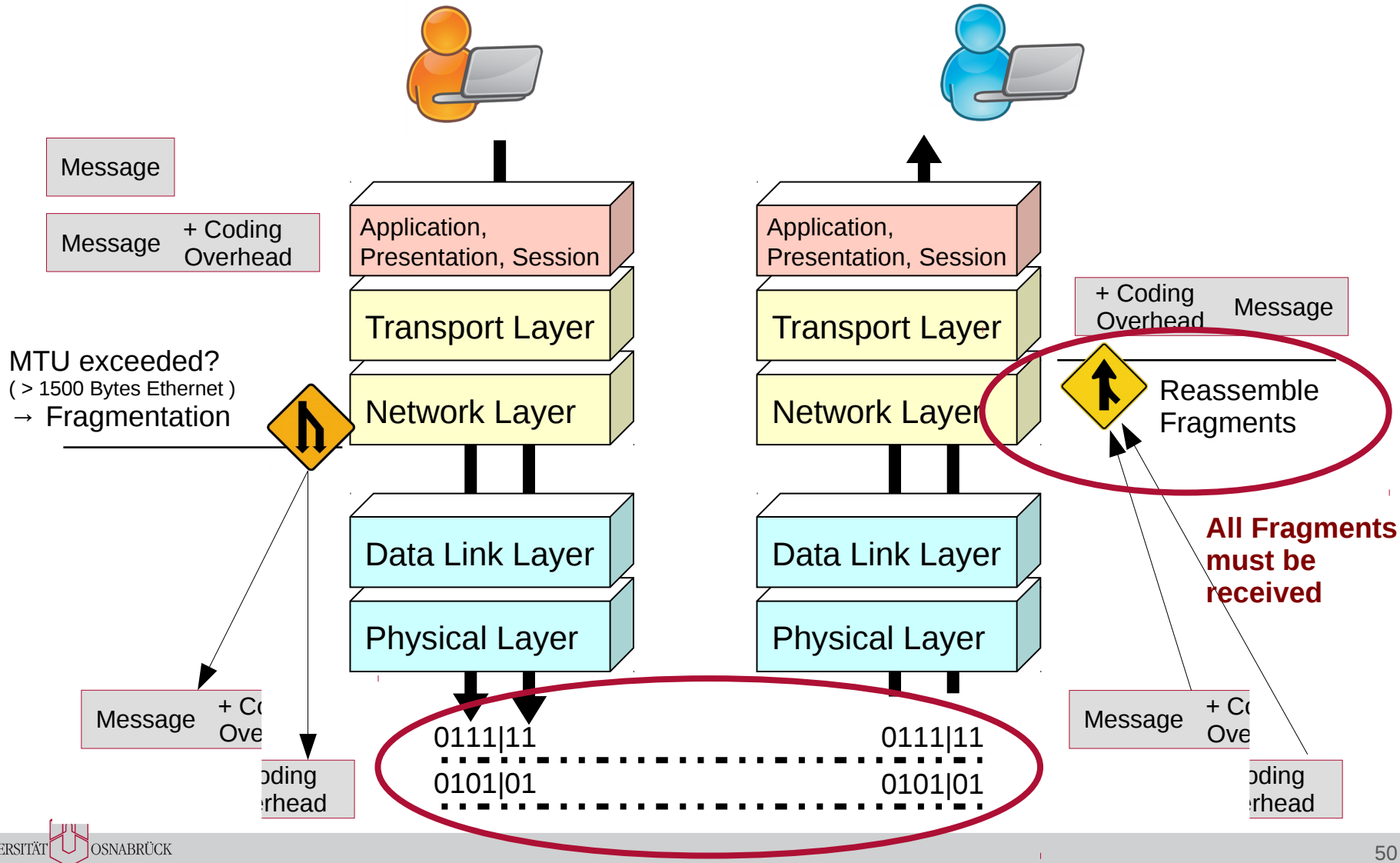
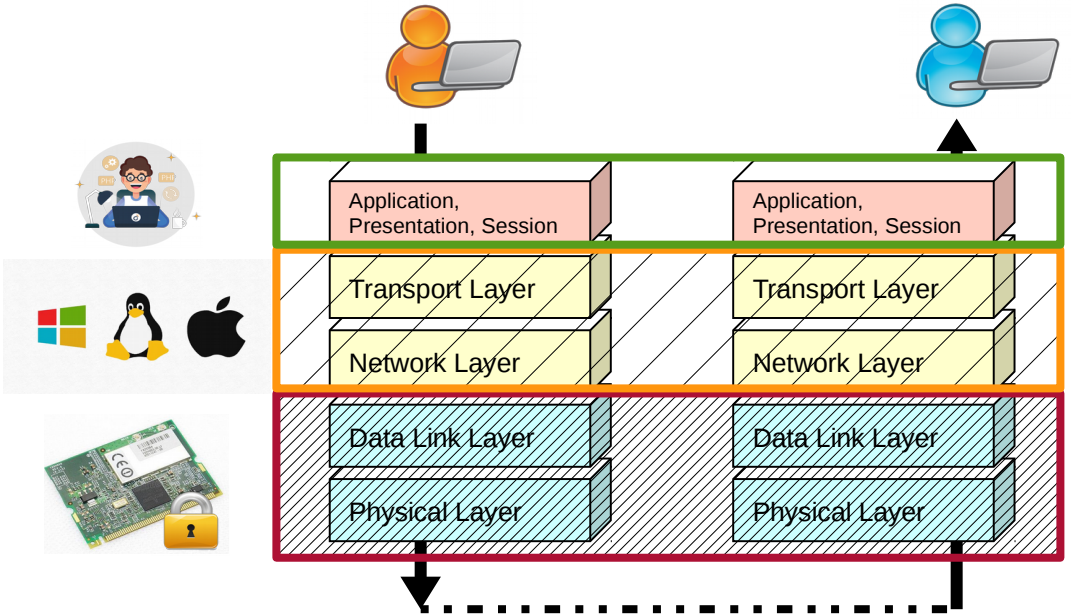
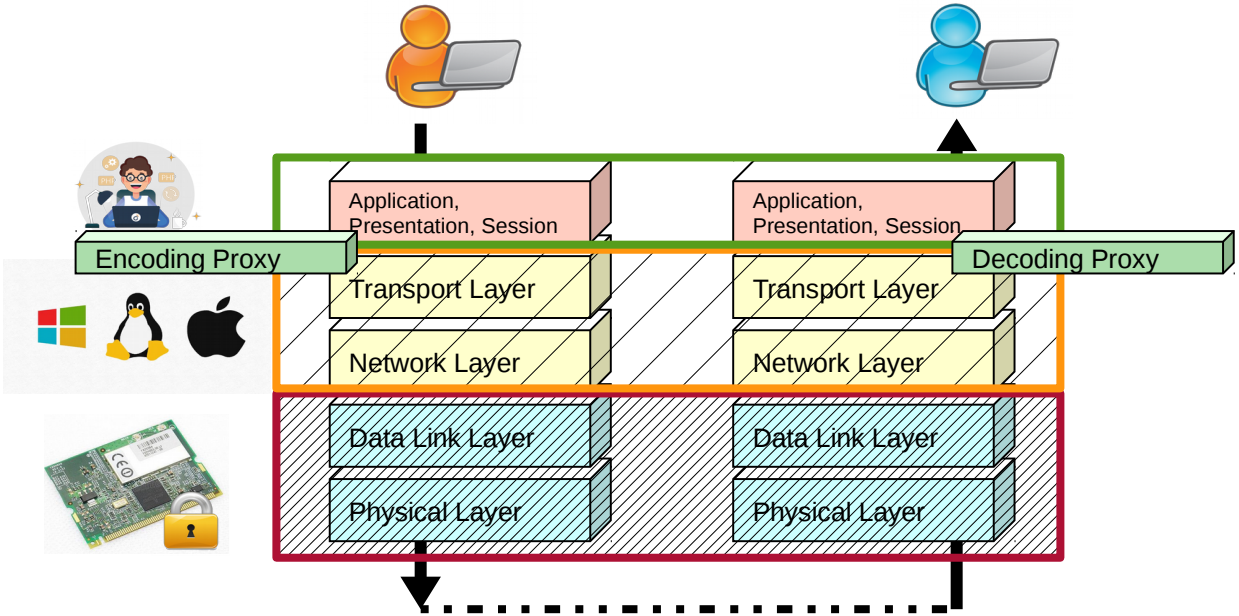


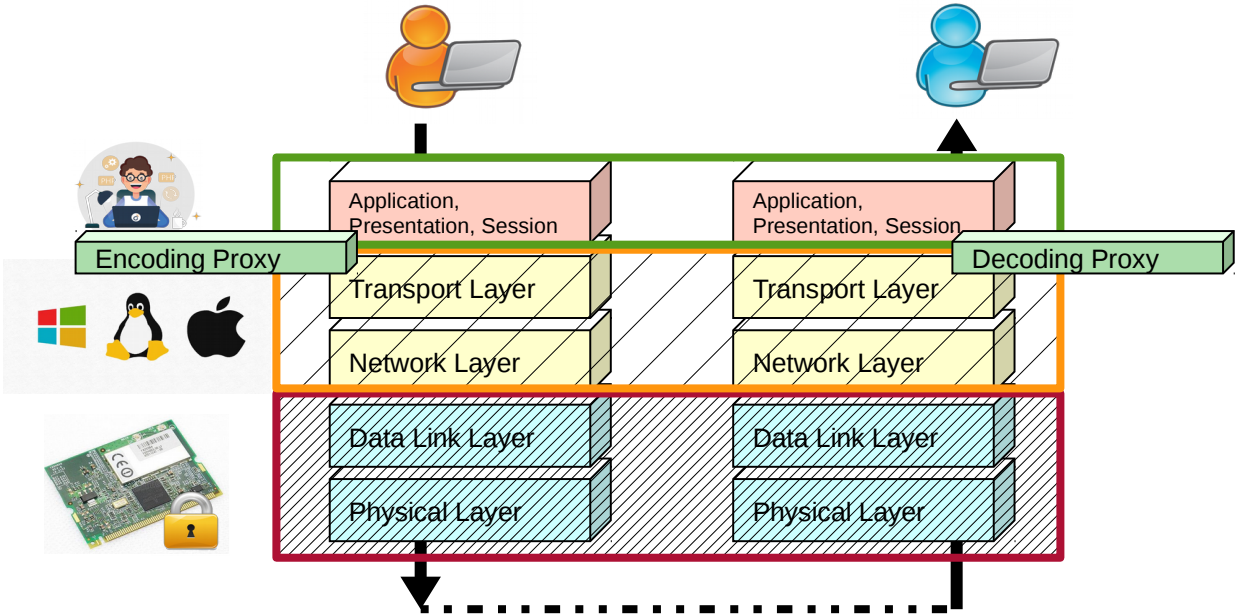
NC Integration:
Proxy Solution



NC Integration:
Proxy Solution



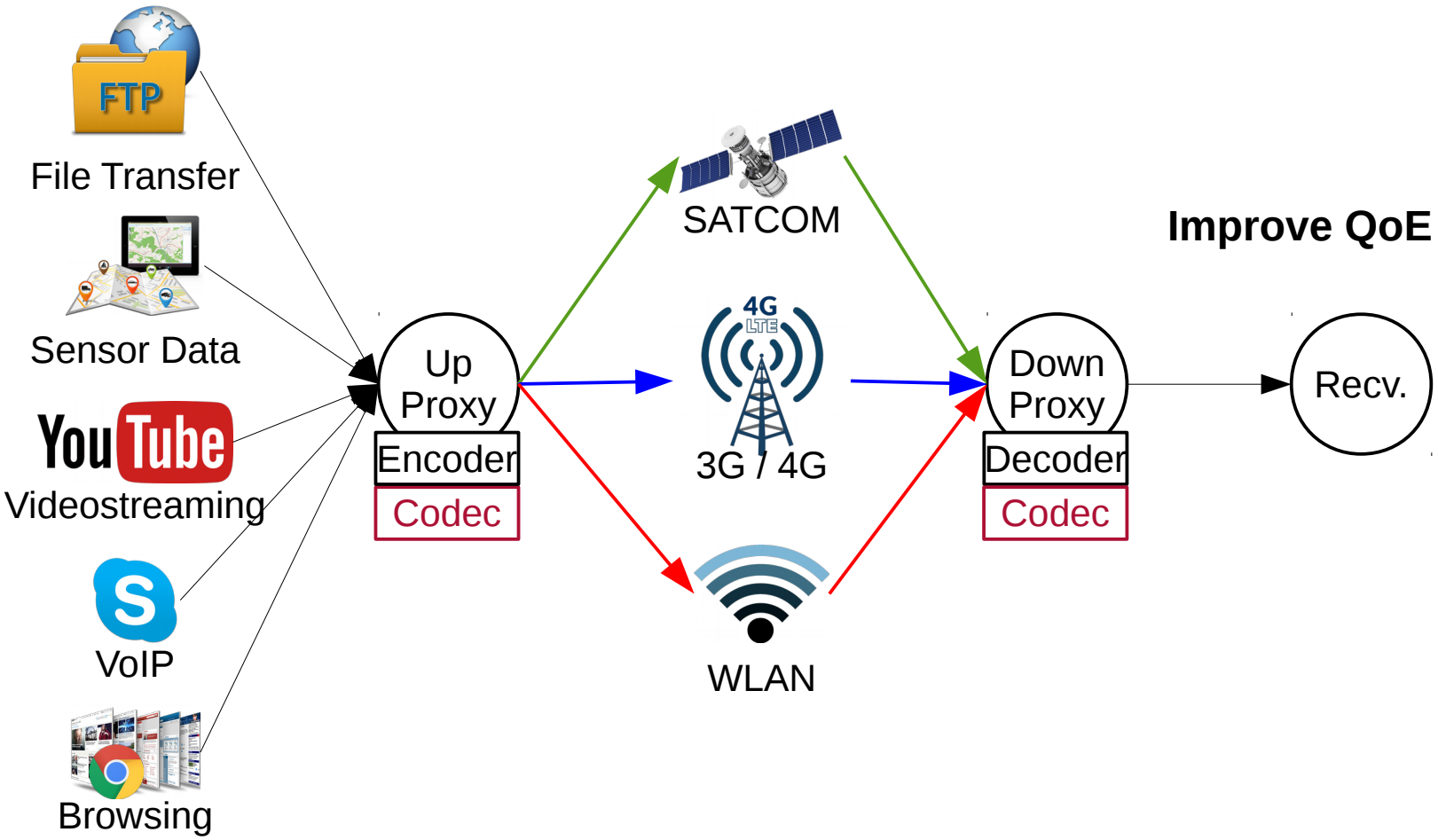
NC Integration:
Proxy Solution



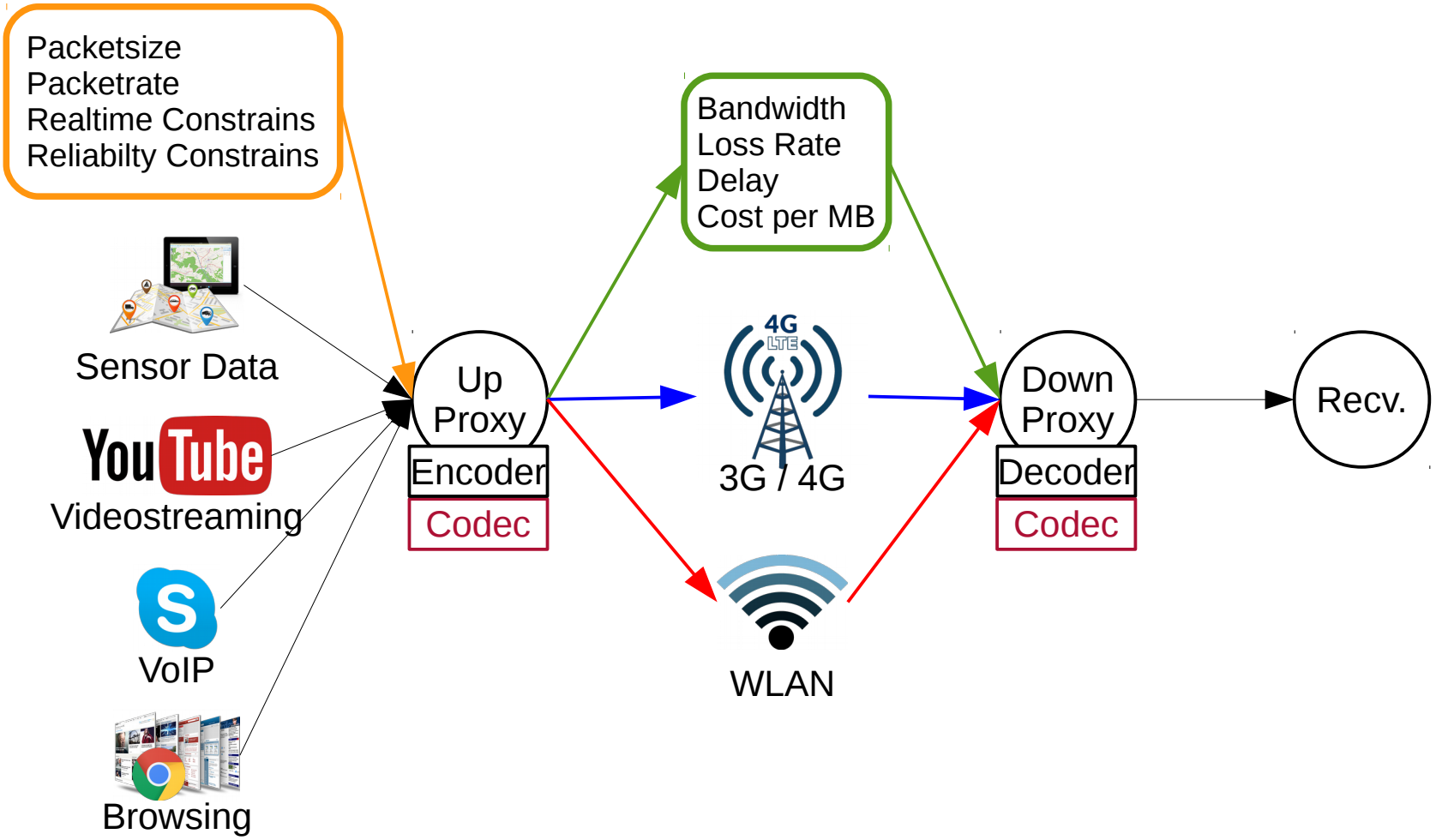
PyNC Proxy

Python-based **N**etwork **C**oding Proxy
using SageMath

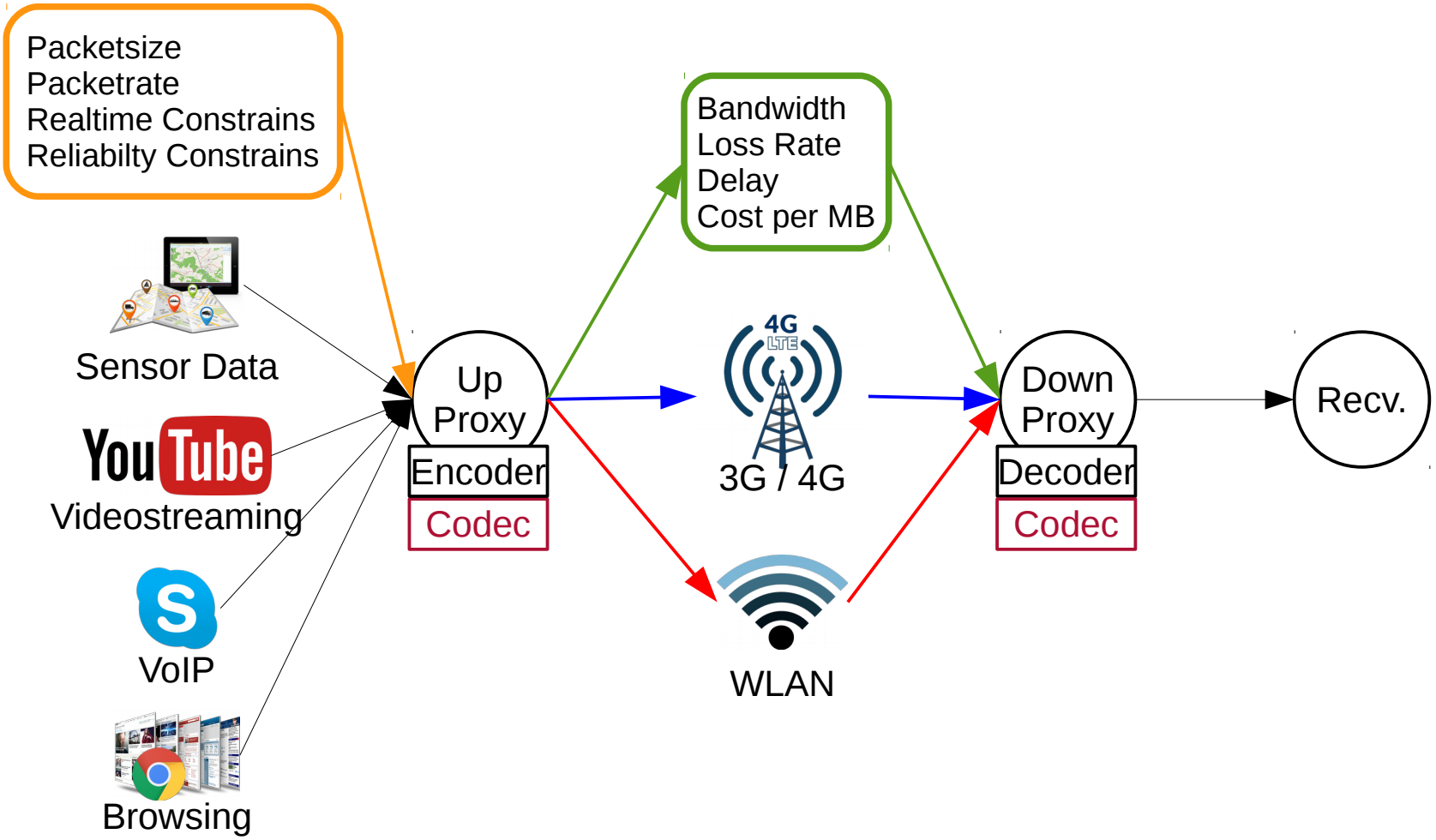
Codec Parameterization



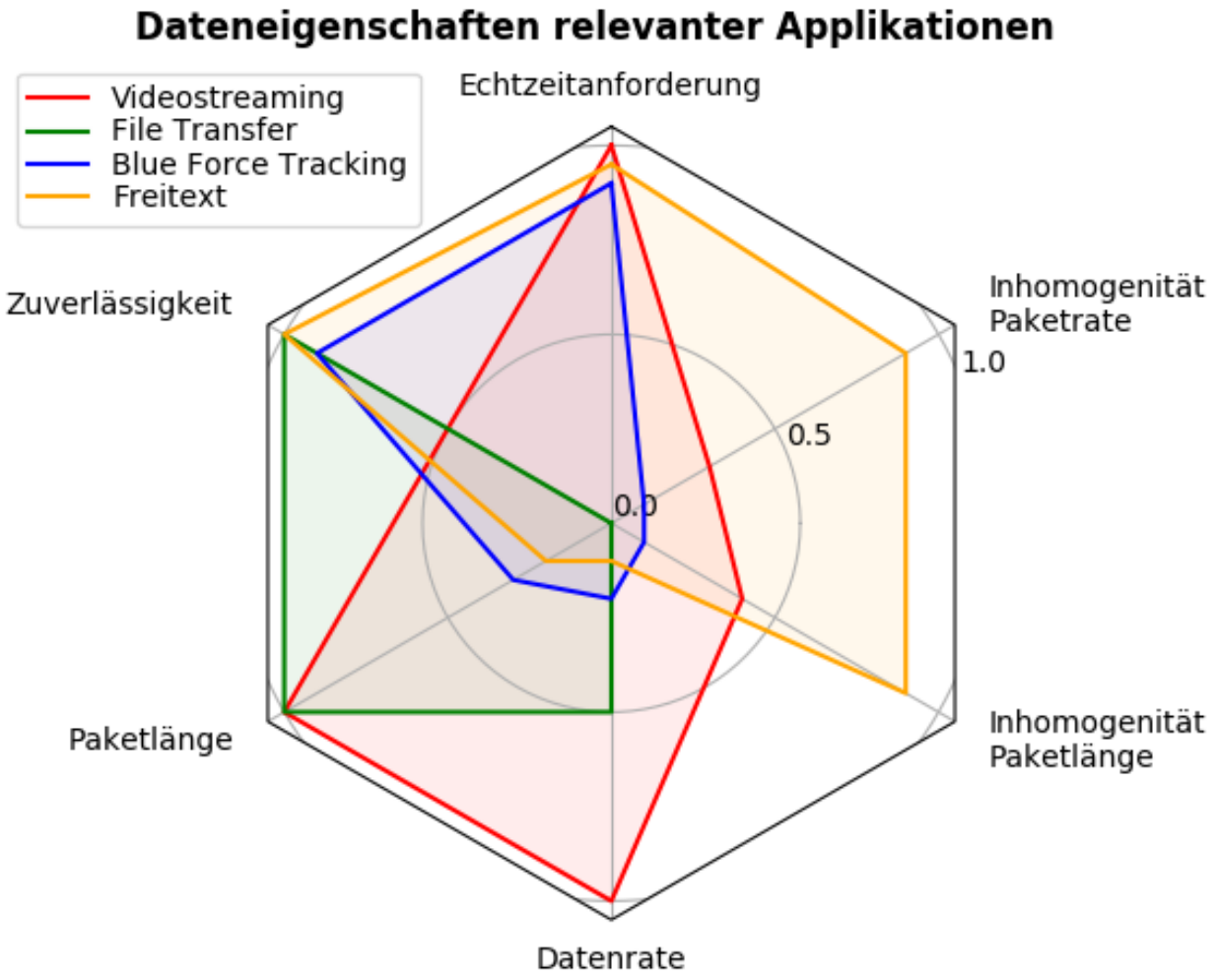
Codec Parameterization



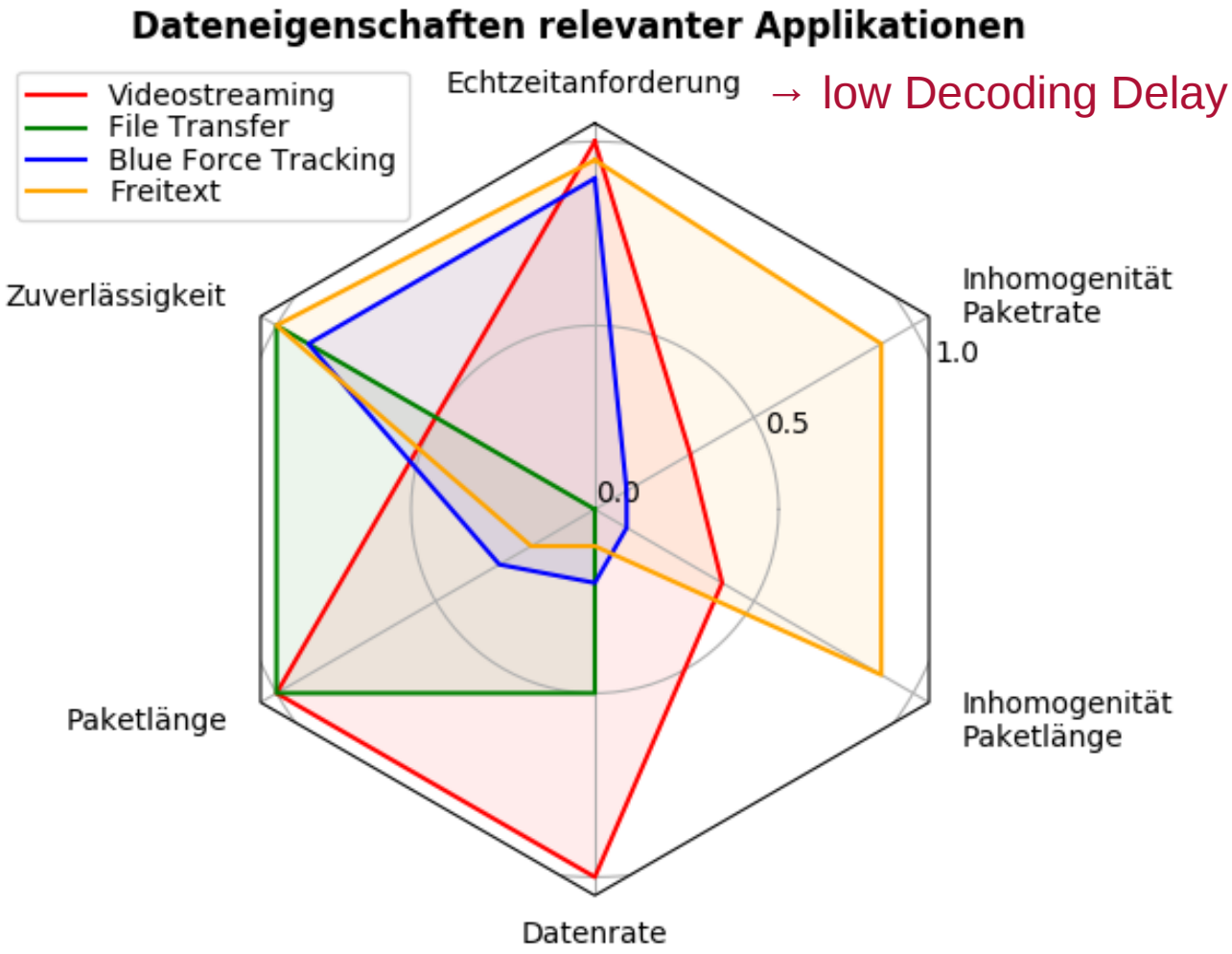
Codec Parameterization



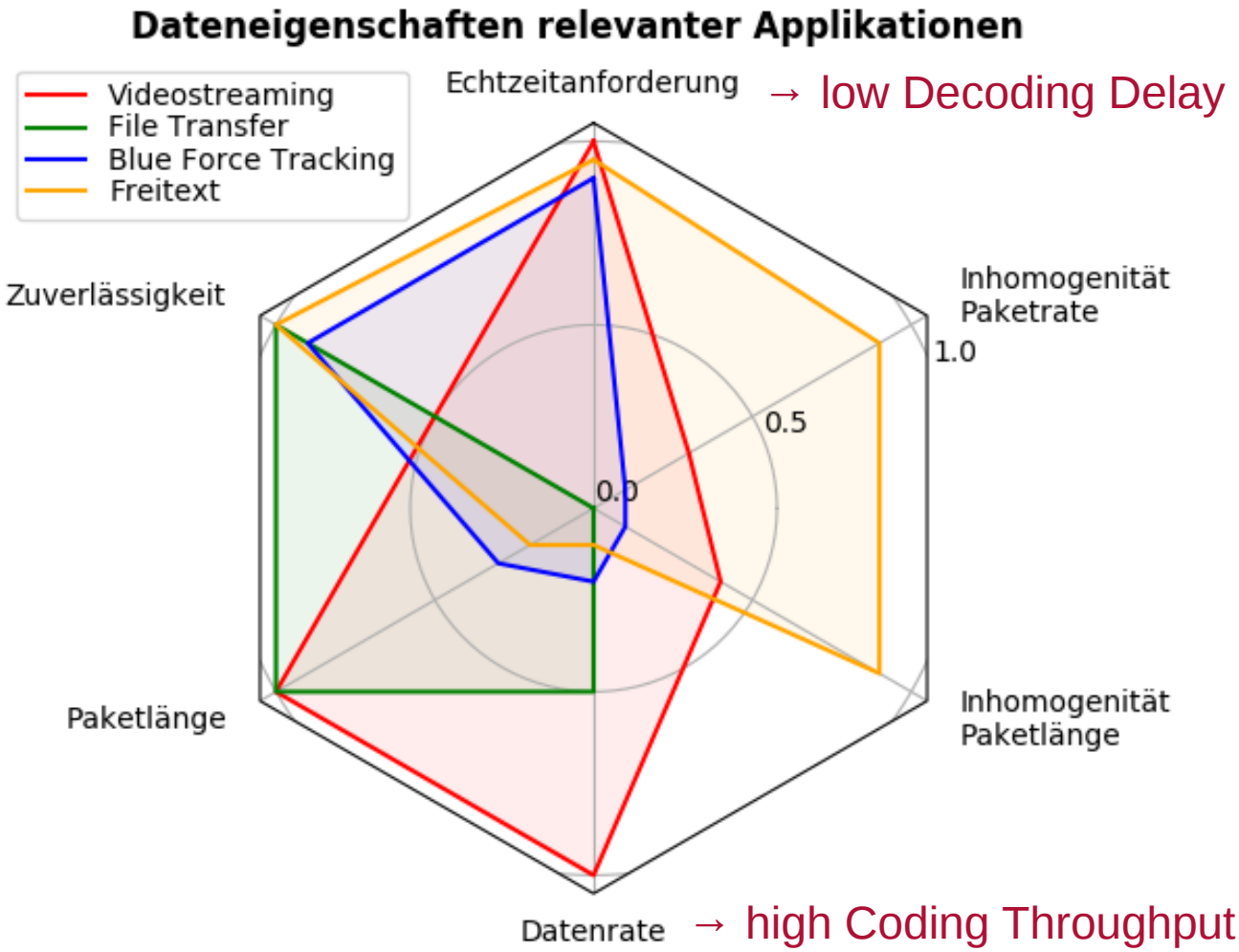
Codec Parameterization



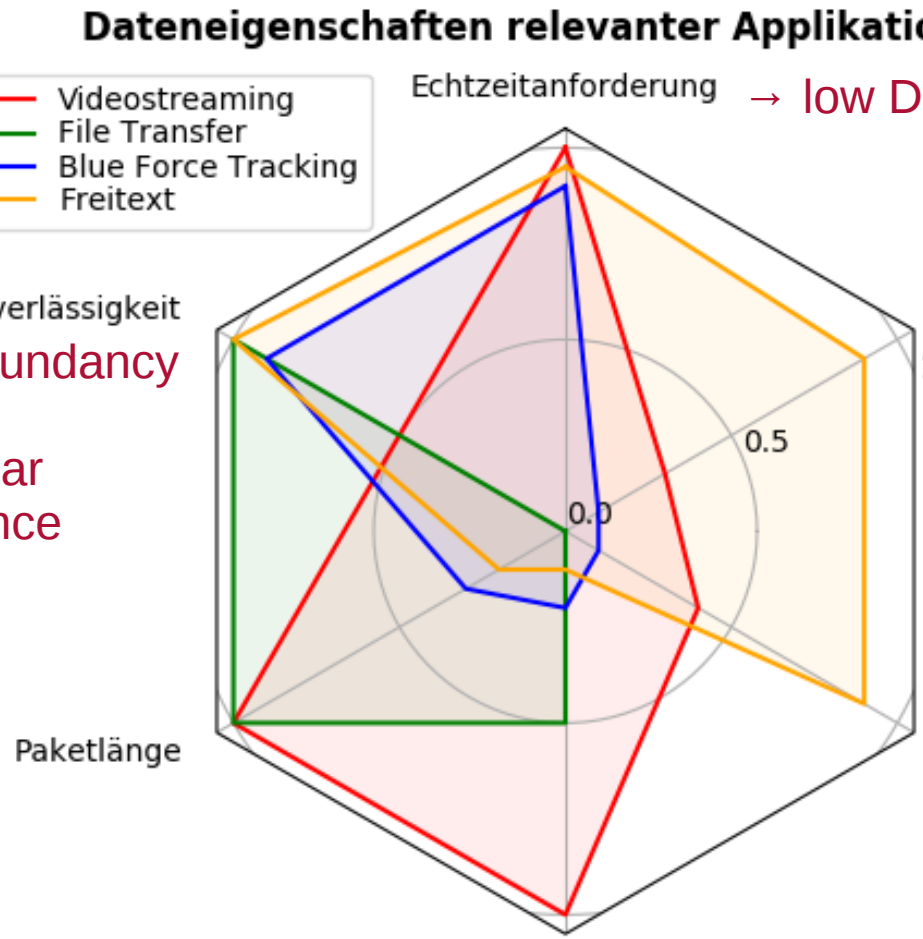
Codec Parameterization



Codec Parameterization



Codec Parameterization



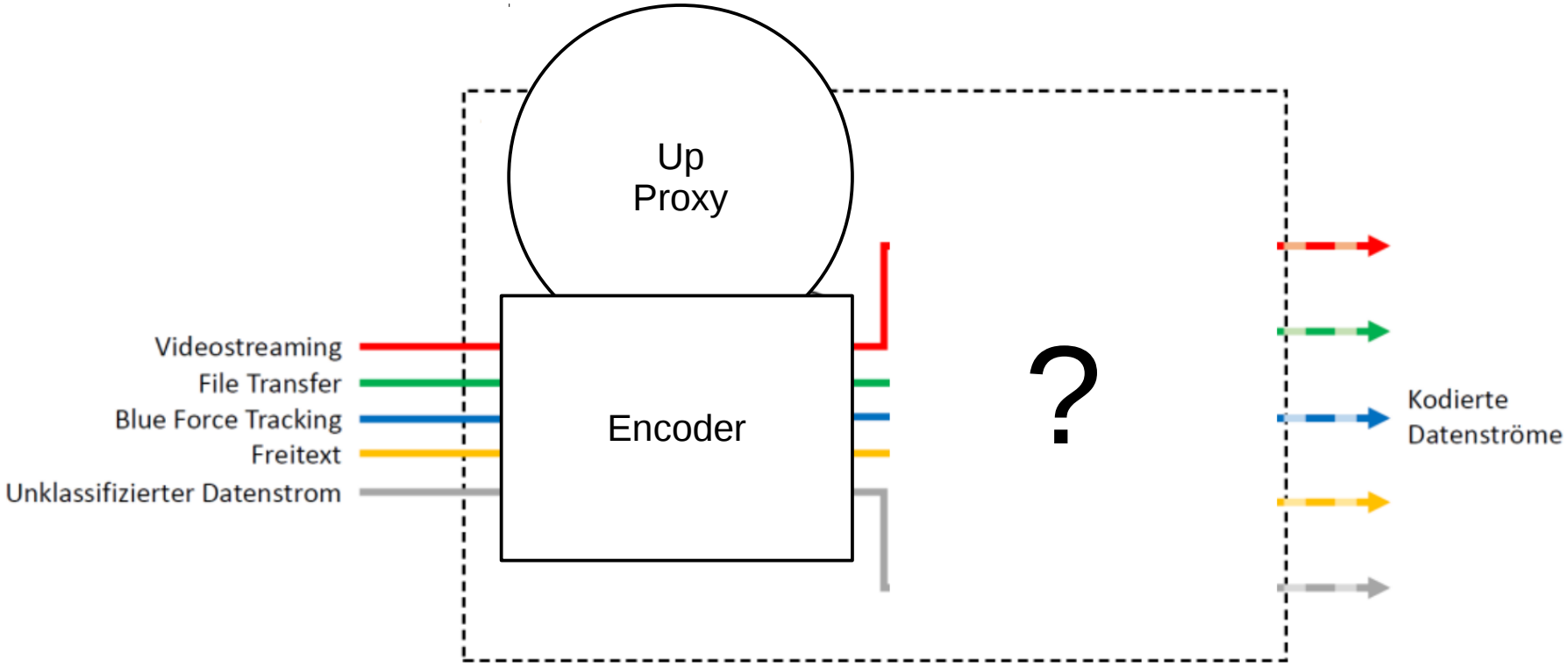
→ low Decoding Delay

→high Redundancy

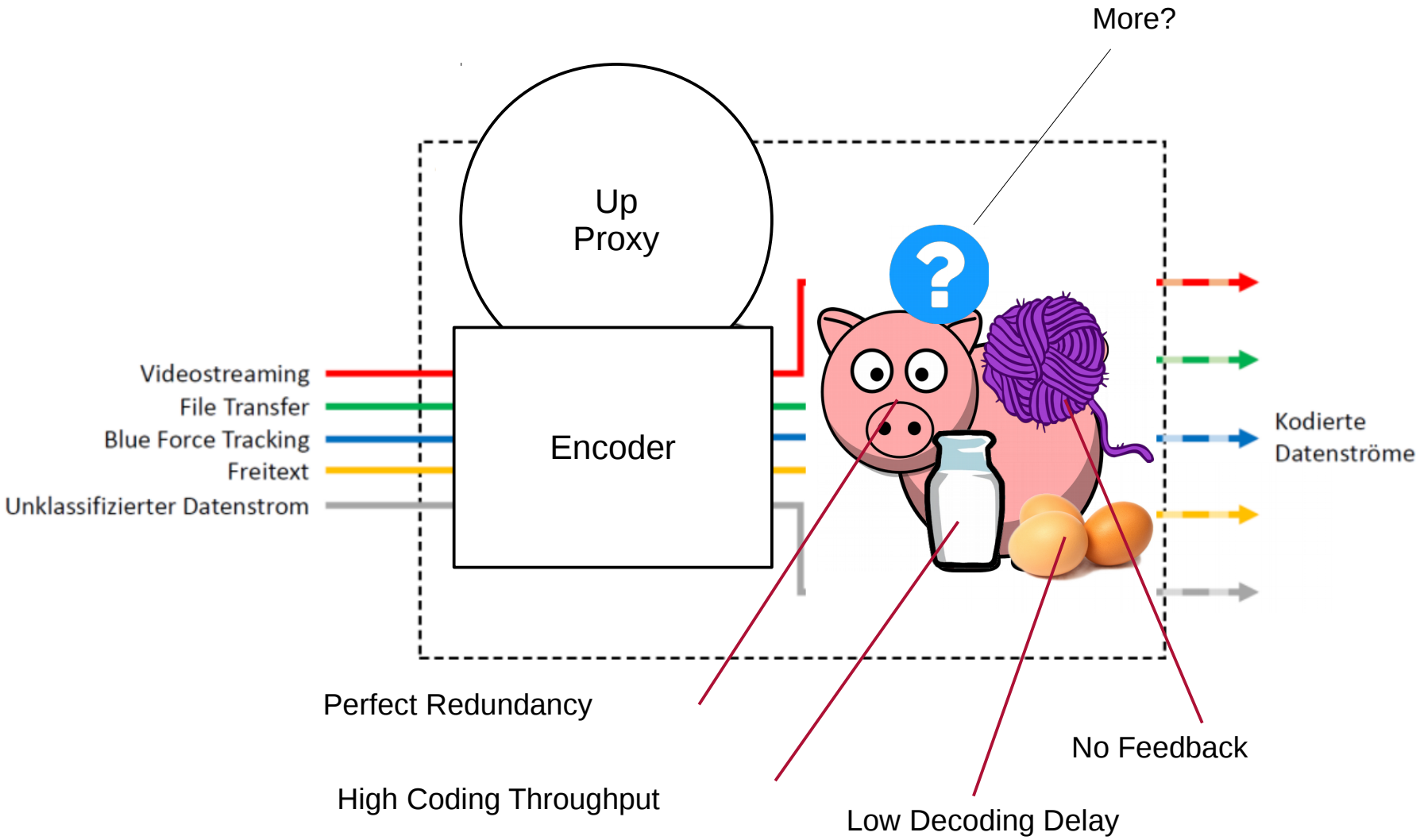
→high Linear Independence

→ high Coding Throughput

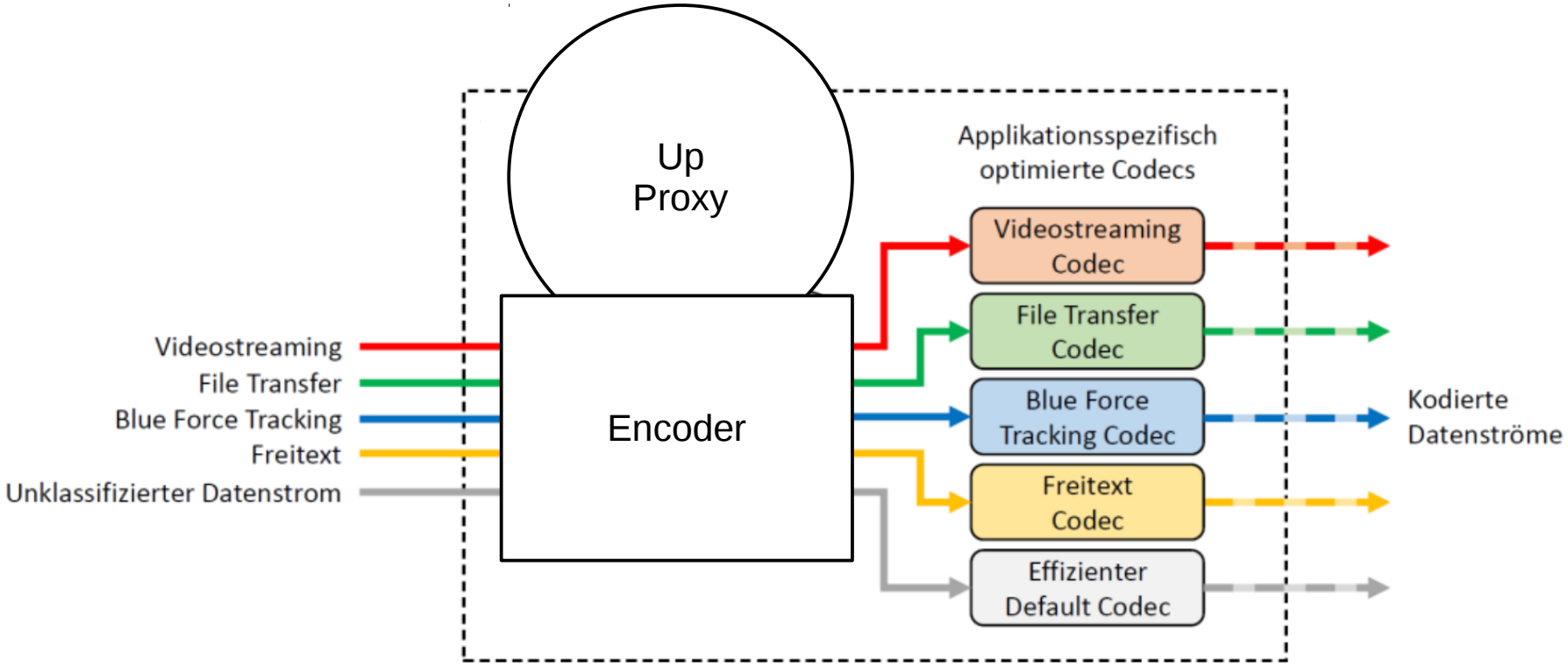
Codec Parameterization



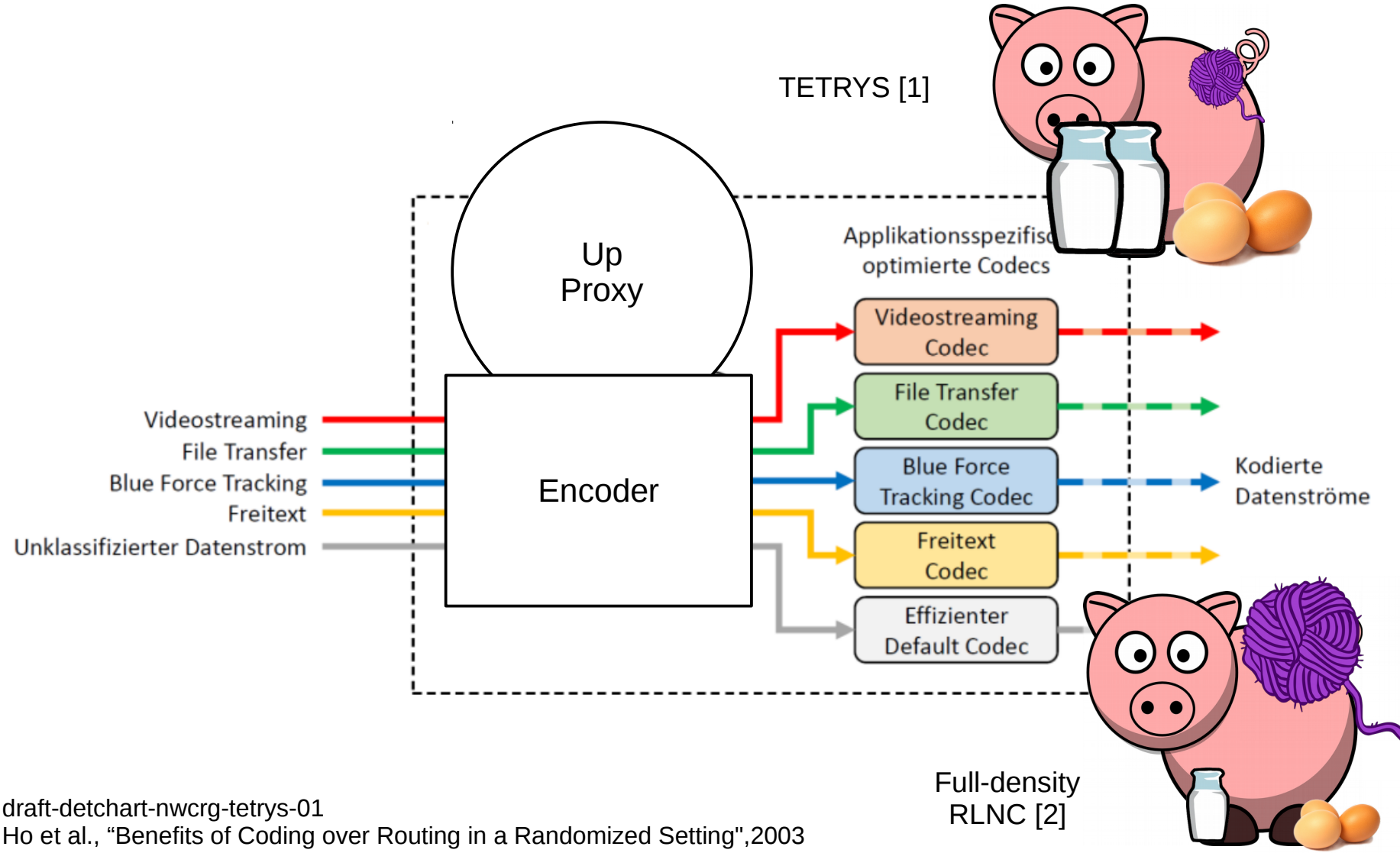
Codec Parameterization



Codec Parameterization

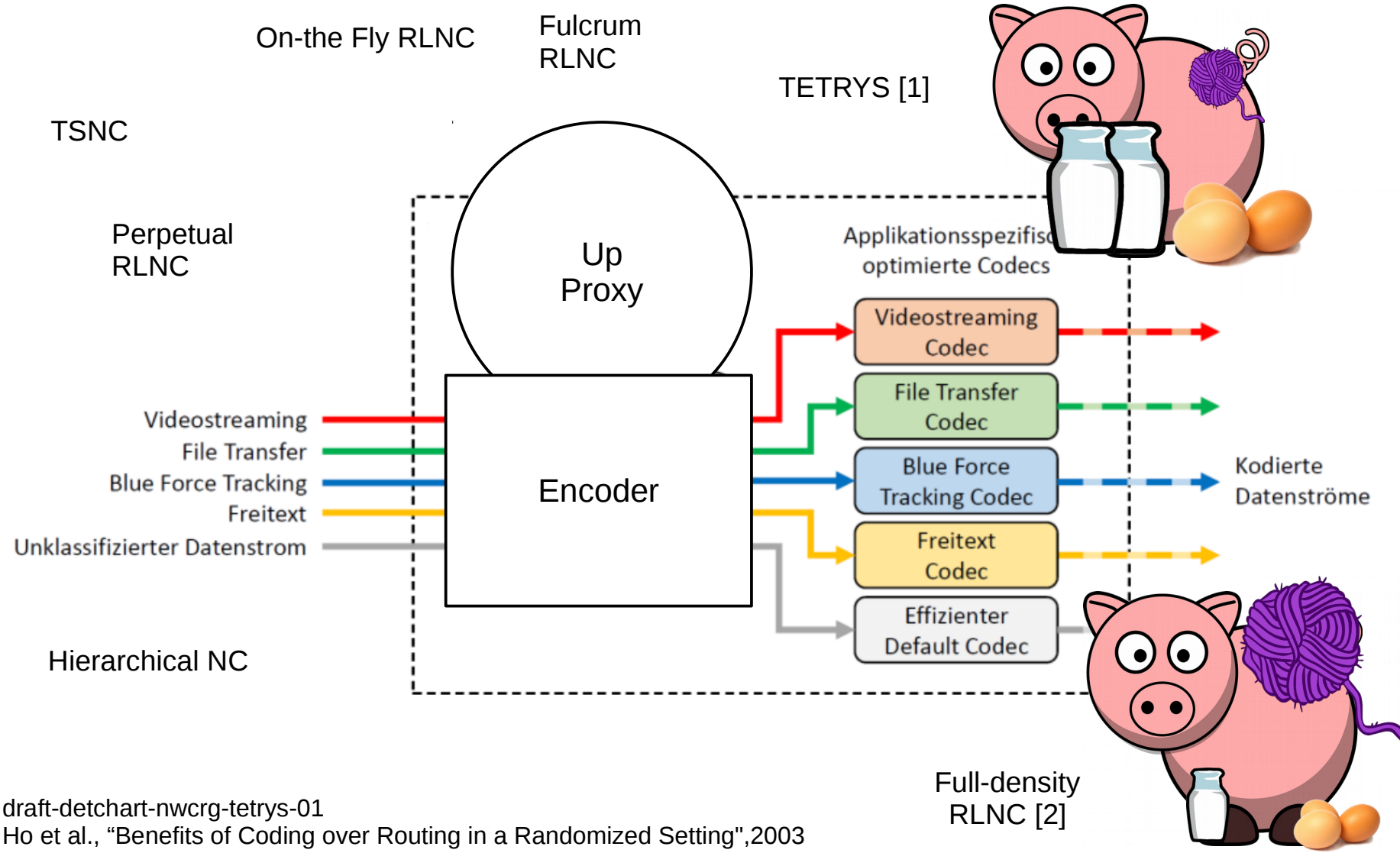


Codec Parameterization



[1] draft-detchart-nwcrg-tetrys-01
[2] Ho et al., “Benefits of Coding over Routing in a Randomized Setting",2003

Codec Parameterization



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“Packet-Preserving Network Coding Schemes for Padding Overhead Reduction”

IEEE LCN 2019, Osnabrueck

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Motivational Scenario

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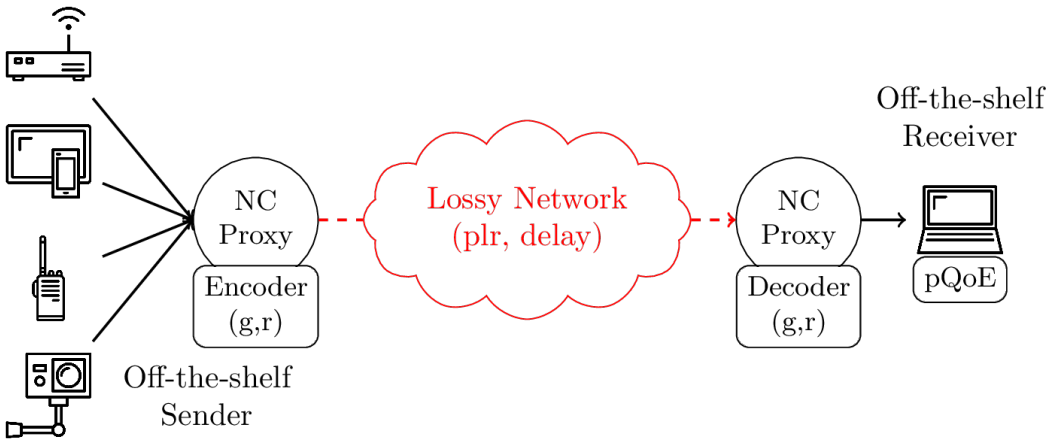
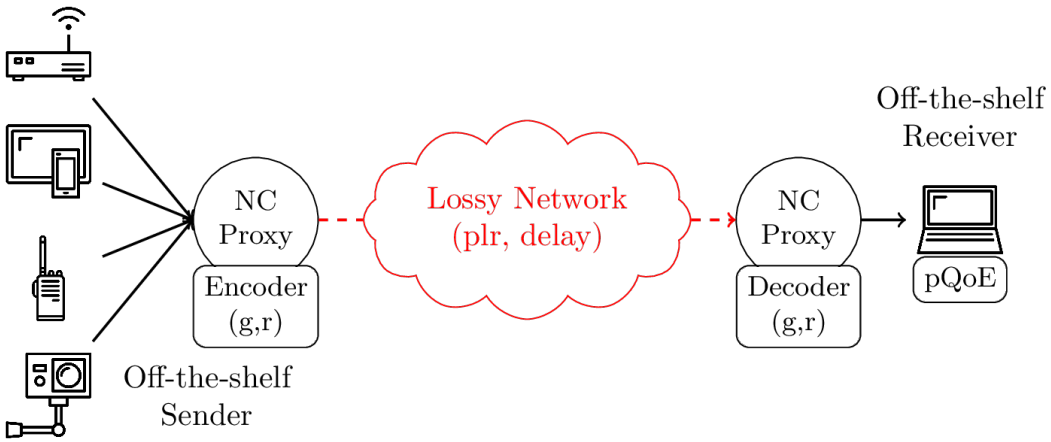
Motivational Scenario

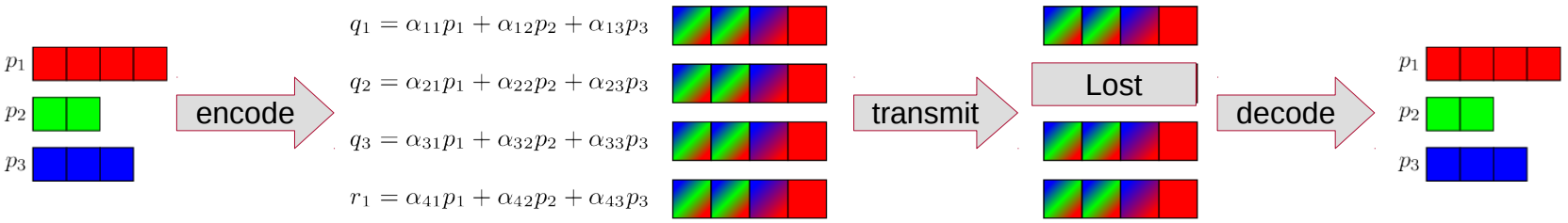
Approach:
Transparent Network Coding Proxy

Add packet level FEC to correct packet loss



Approach:
Transparent Network Coding Proxy
Add packet level FEC to correct packet loss





Approach:
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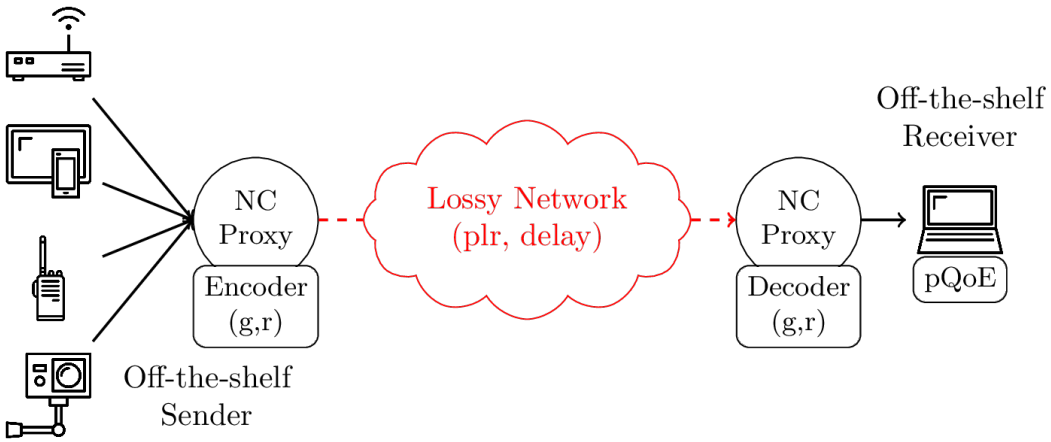
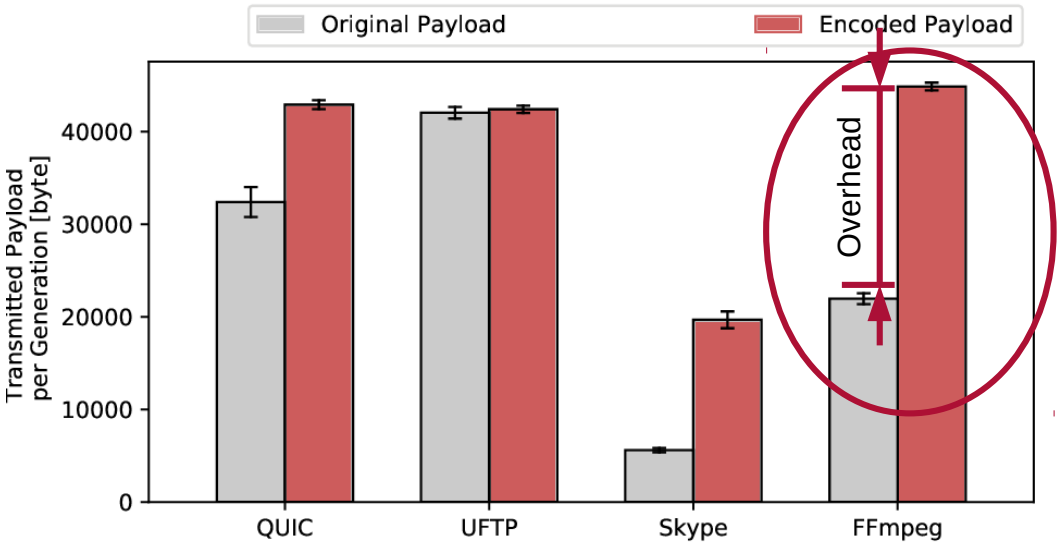
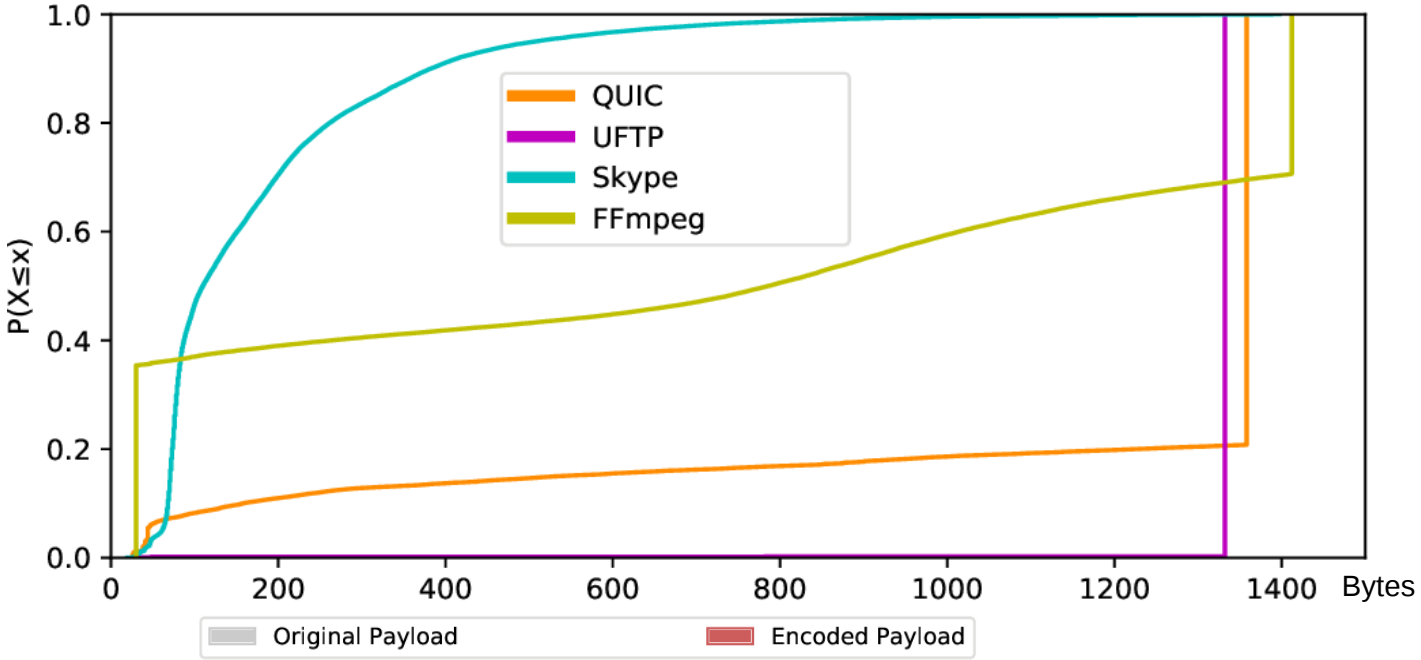
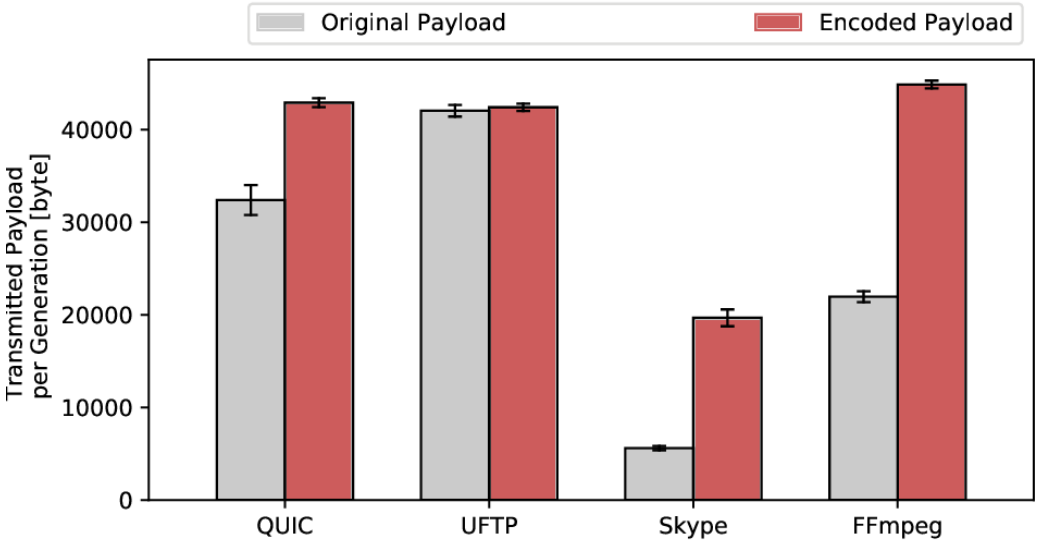




Observed problem:
- More data send than expected if coding used

Packet Length Distributions



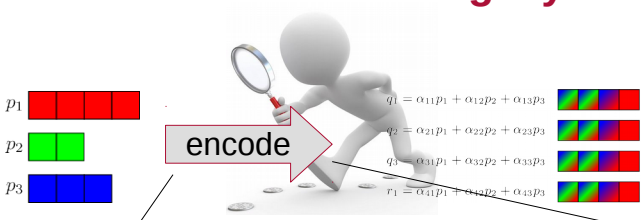


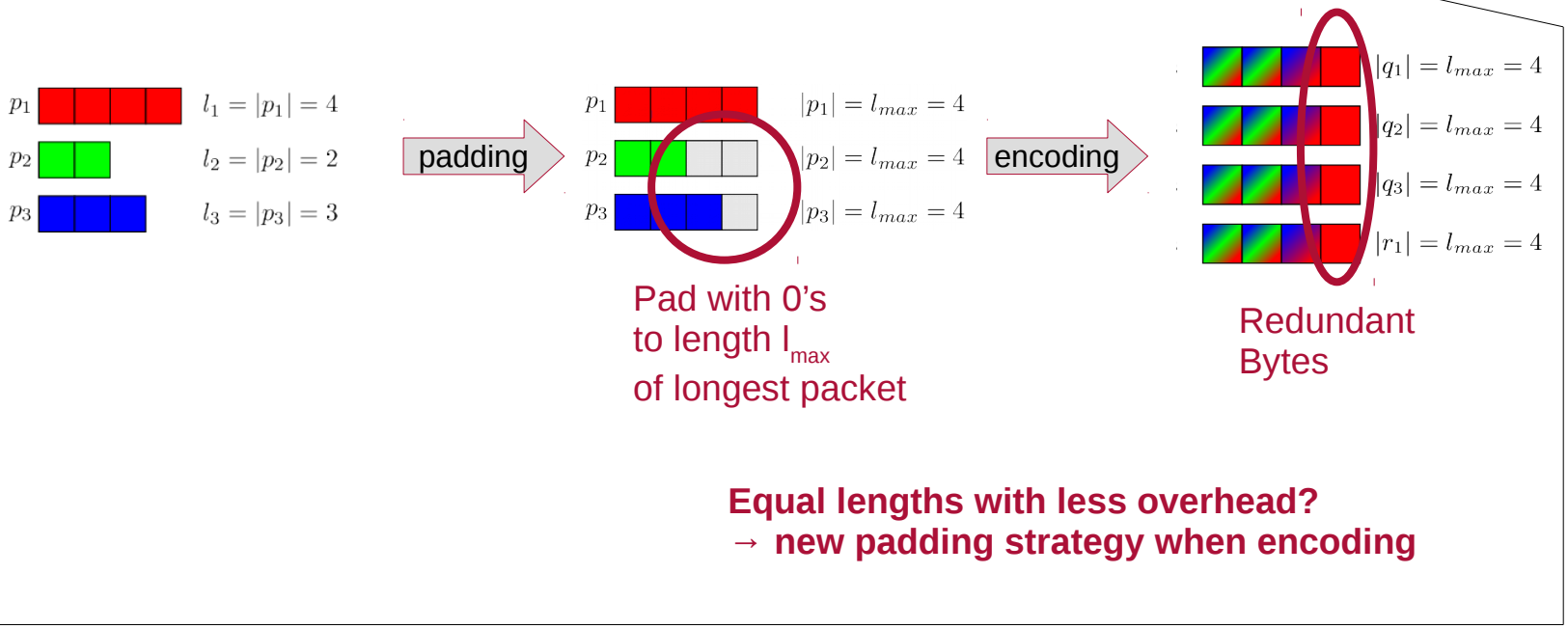
Known by Compta et al.:

Packet length heterogeinity

Padding overhead

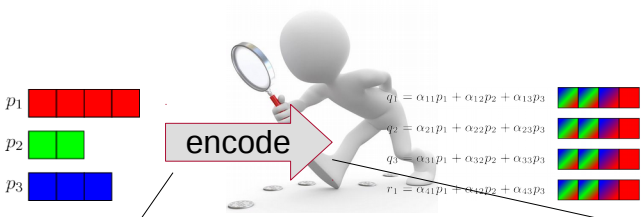
Legacy: Traditional RLNC with pre-padding:

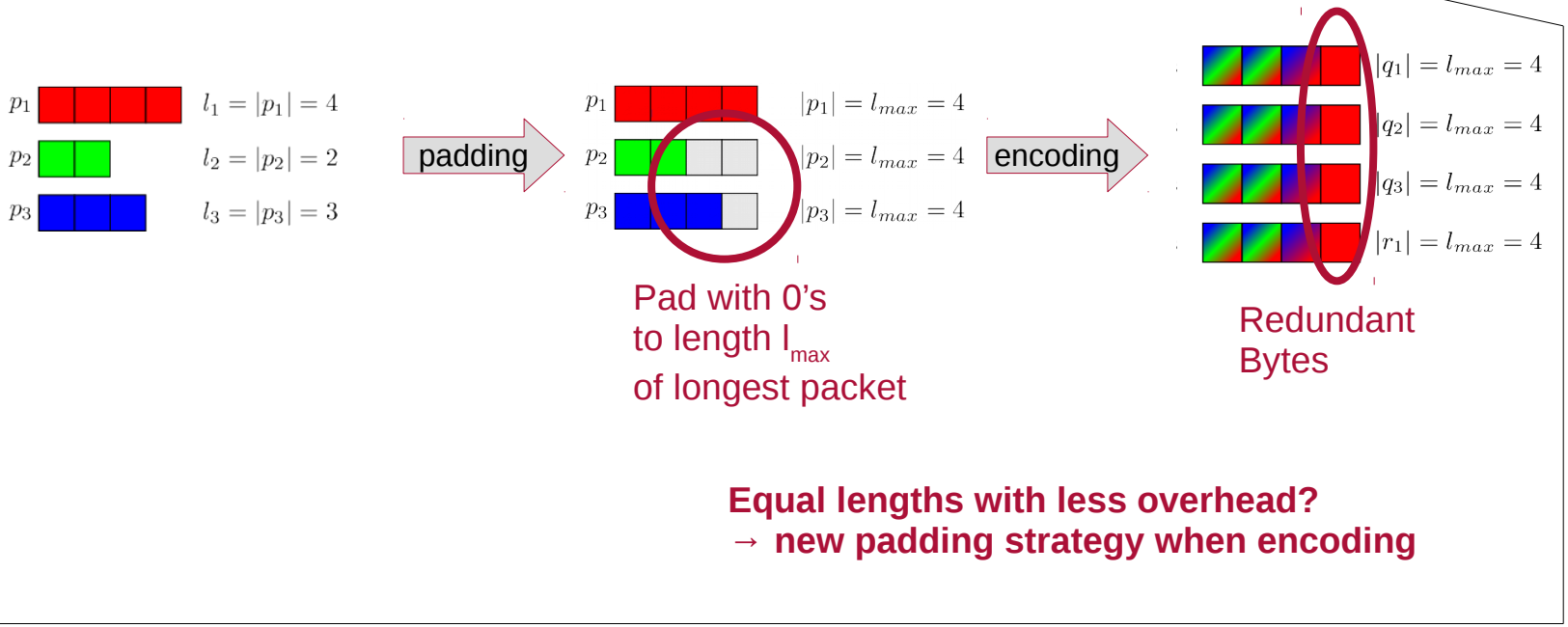




Equal lengths with less overhead?
→ new padding strategy when encoding

Traditional RLNC with pre-padding:

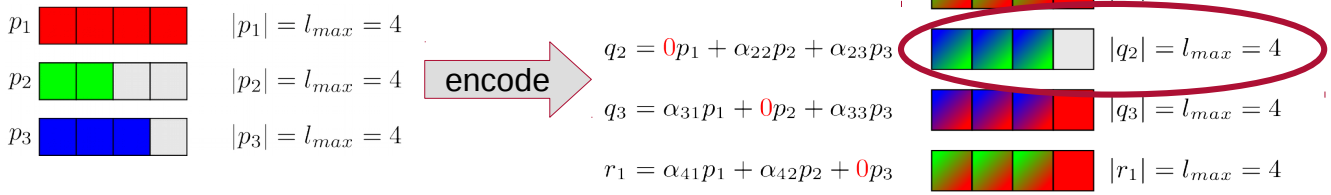




Equal lengths with less overhead?
→ new padding strategy when encoding

Approach 1: Sparse Coding with padding on-demand

Sparse Coding with traditional pre-padding:



Approach 1: Sparse Coding with padding on-demand

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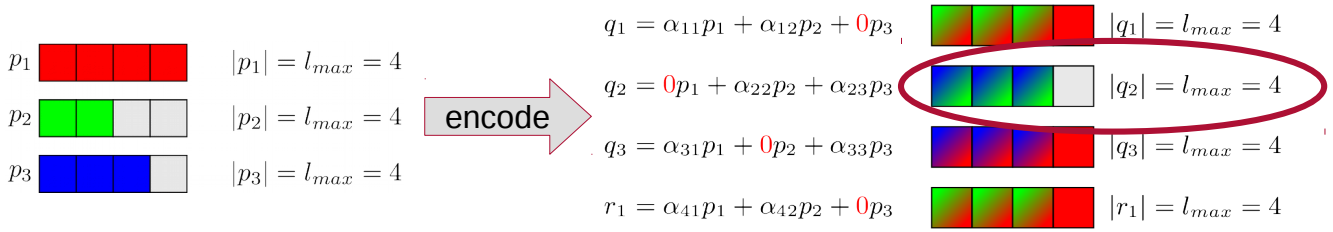
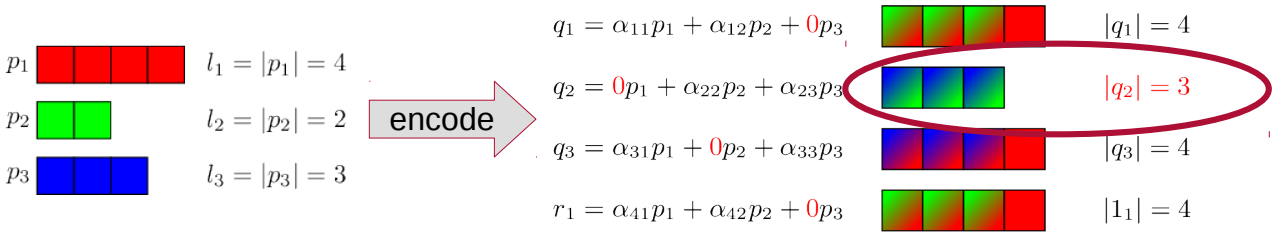


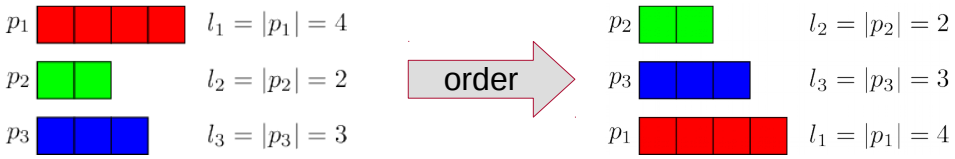
With padding on-demand:

Only pad when packet packet is used → $l_{max} = l_{max}(\text{used})$



Approach 2: Size-based Coding with padding on-demand

Order packets ascending by length:



Approach 2: Size-based Coding with padding on-demand

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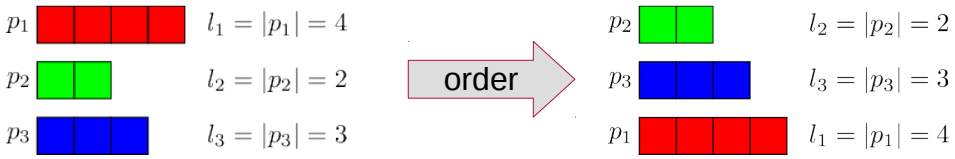
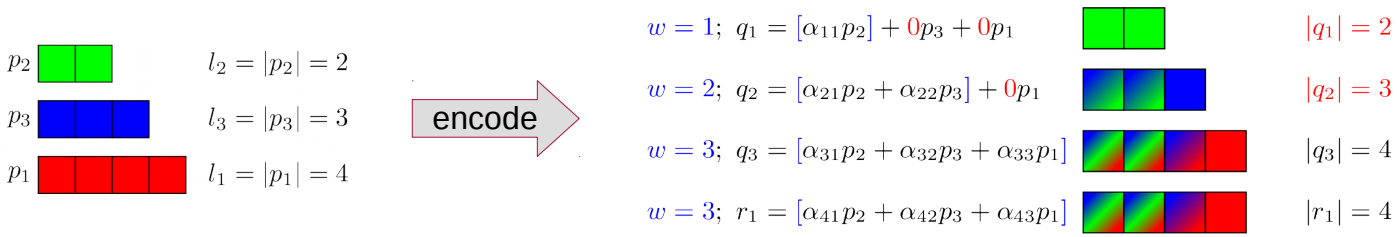


Use growing encoding window:



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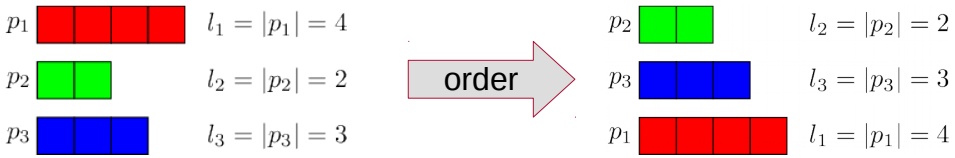
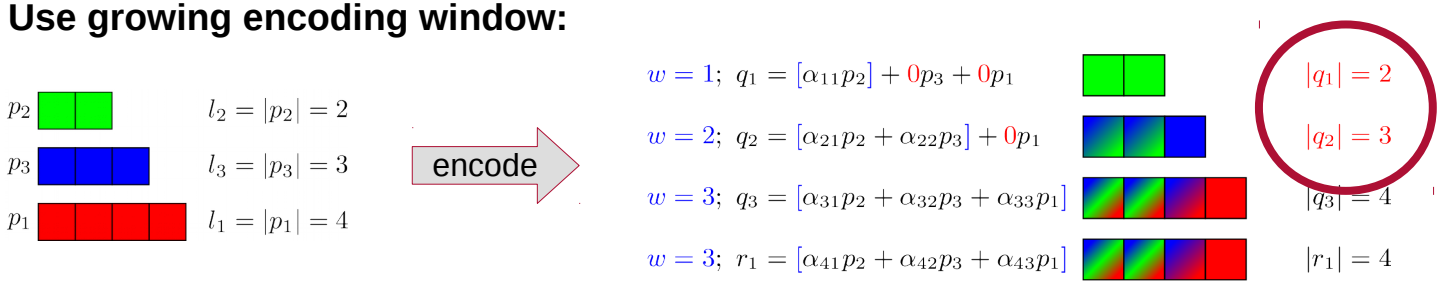
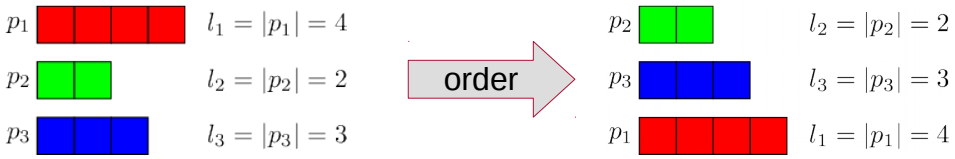


Use growing encoding window:

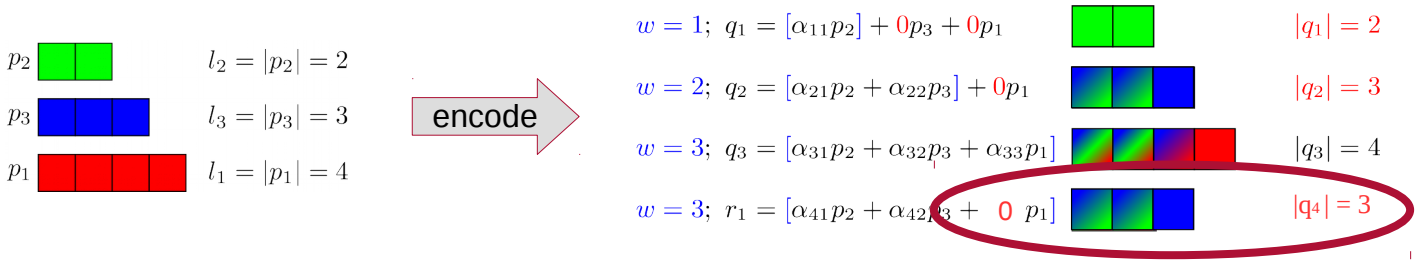


Approach 3: Sparse Size-based Coding with padding on-demand

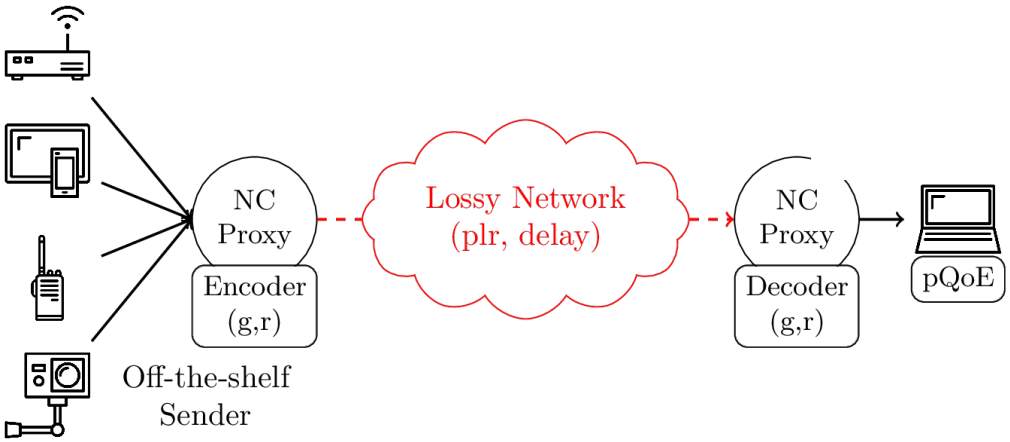
Order packets ascending by length:



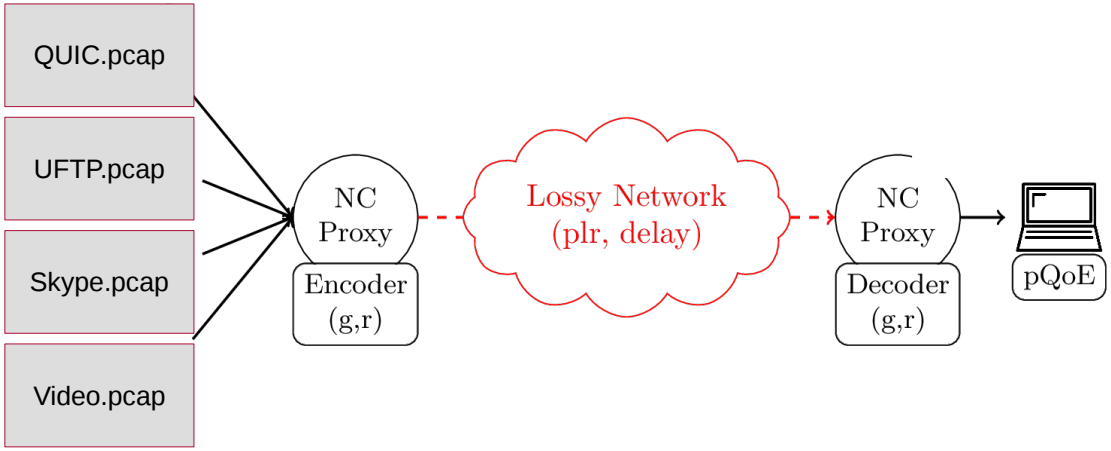
Use sparse growing encoding window:



Evaluation Setup: Trace-based Simulation



Evaluation Setup: Trace-based Simulation



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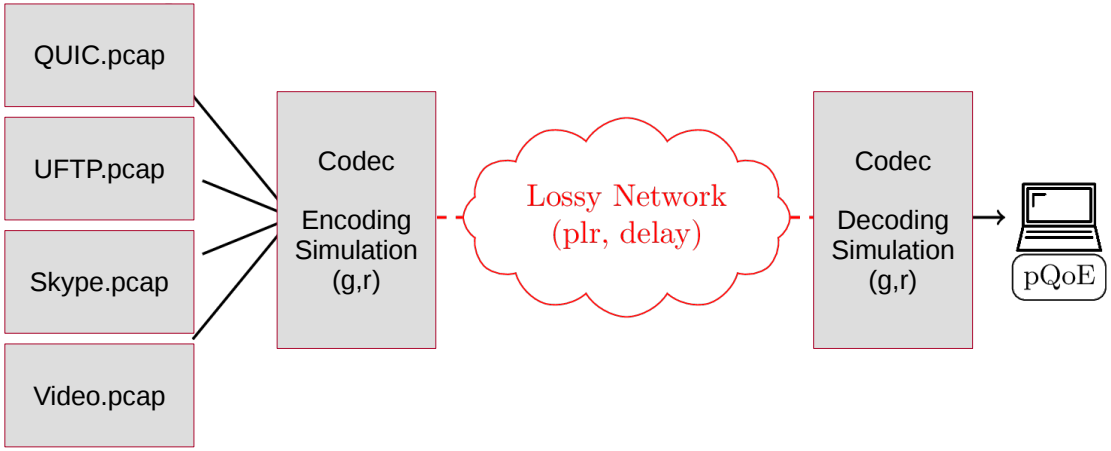
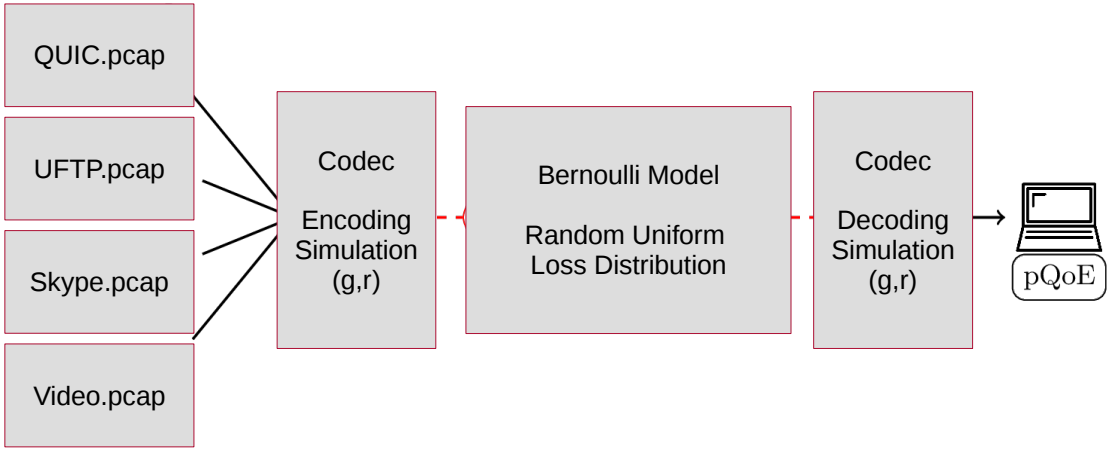
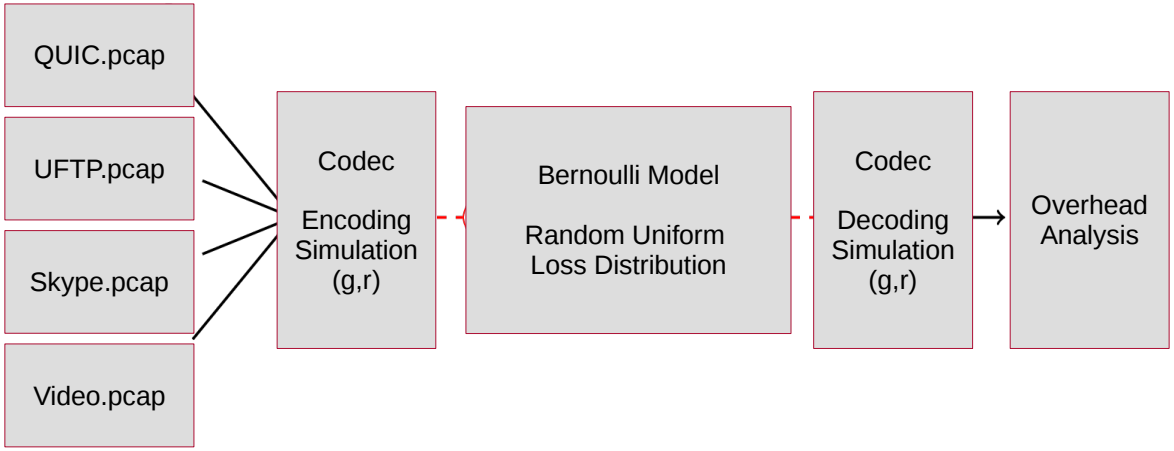


Evaluation Setup: Trace-based Simulation

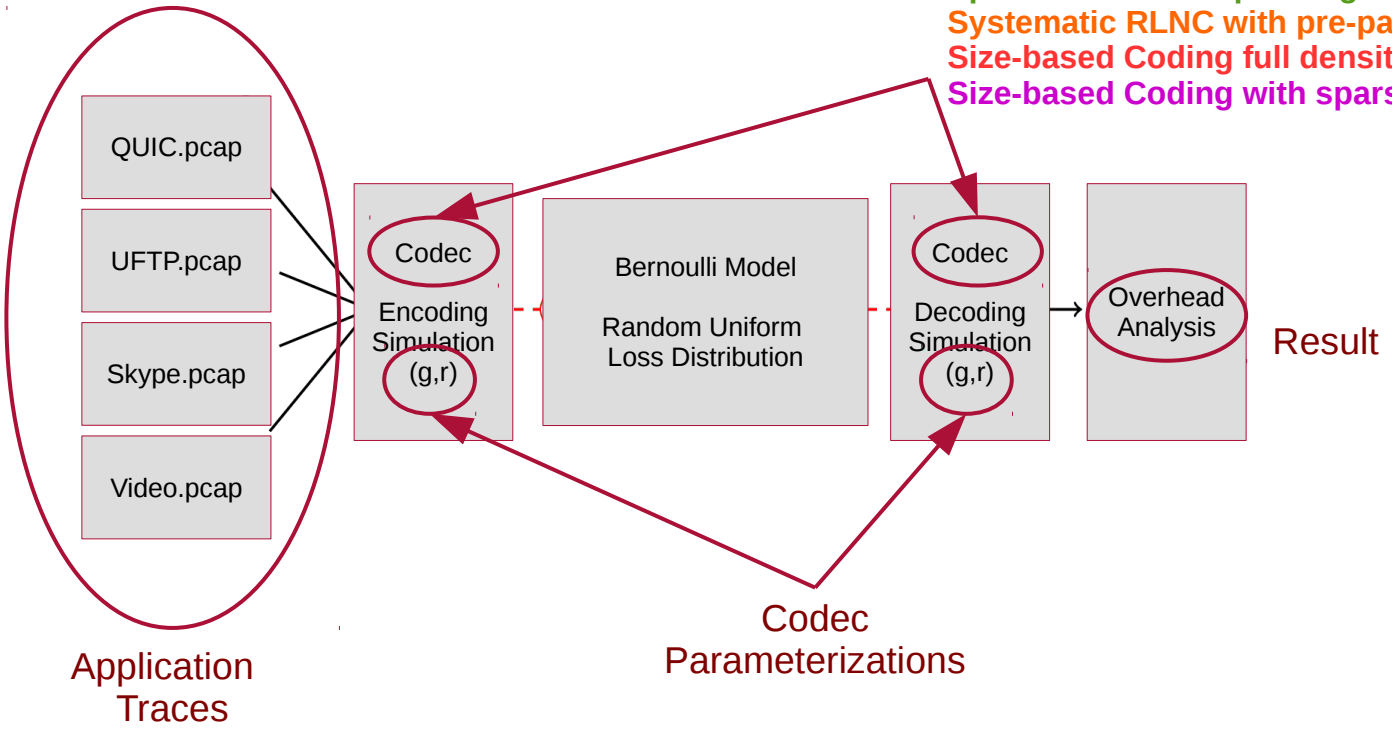


Evaluation Setup: Trace-based Simulation

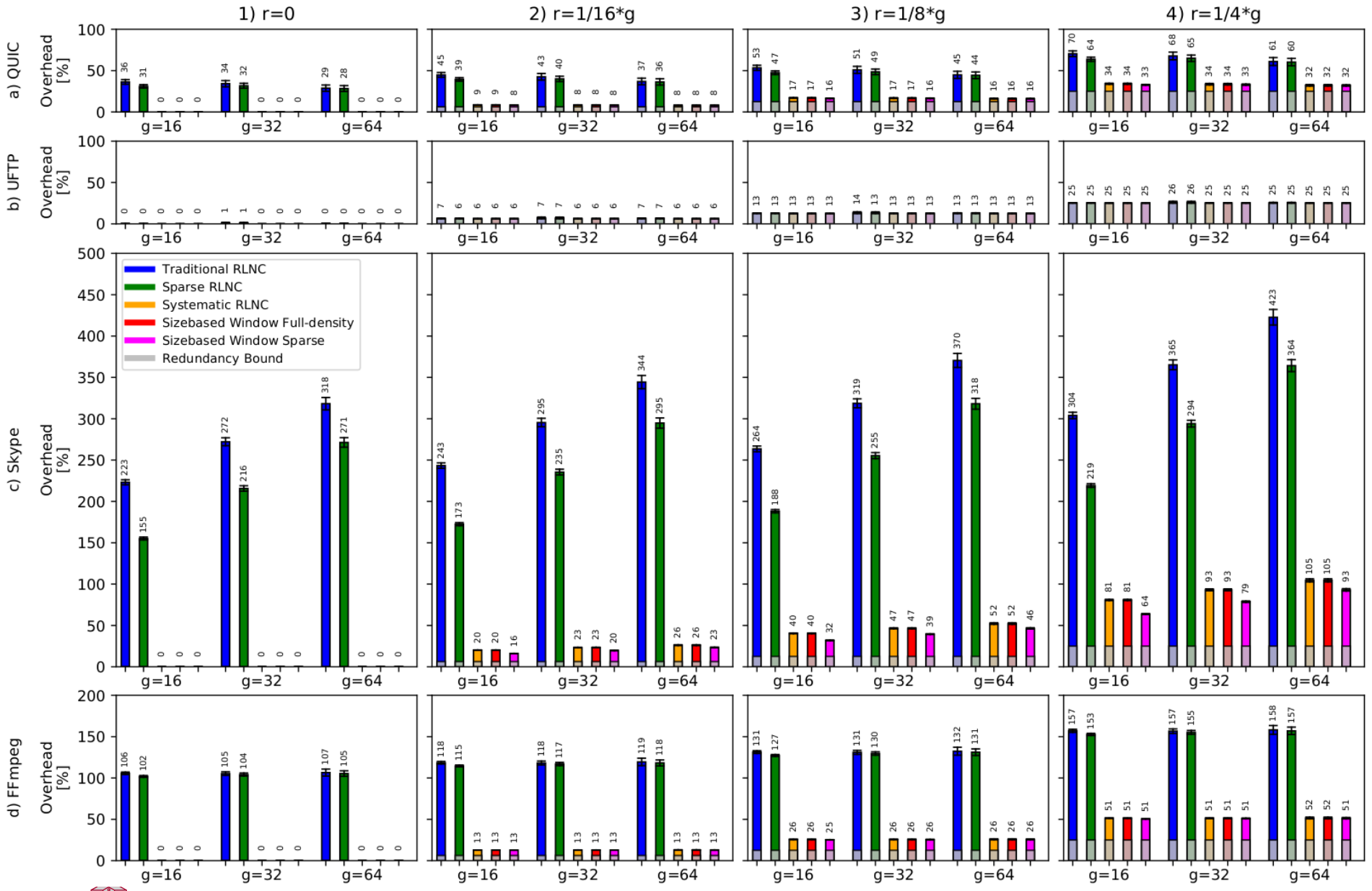


Evaluation Setup: Trace-based Simulation

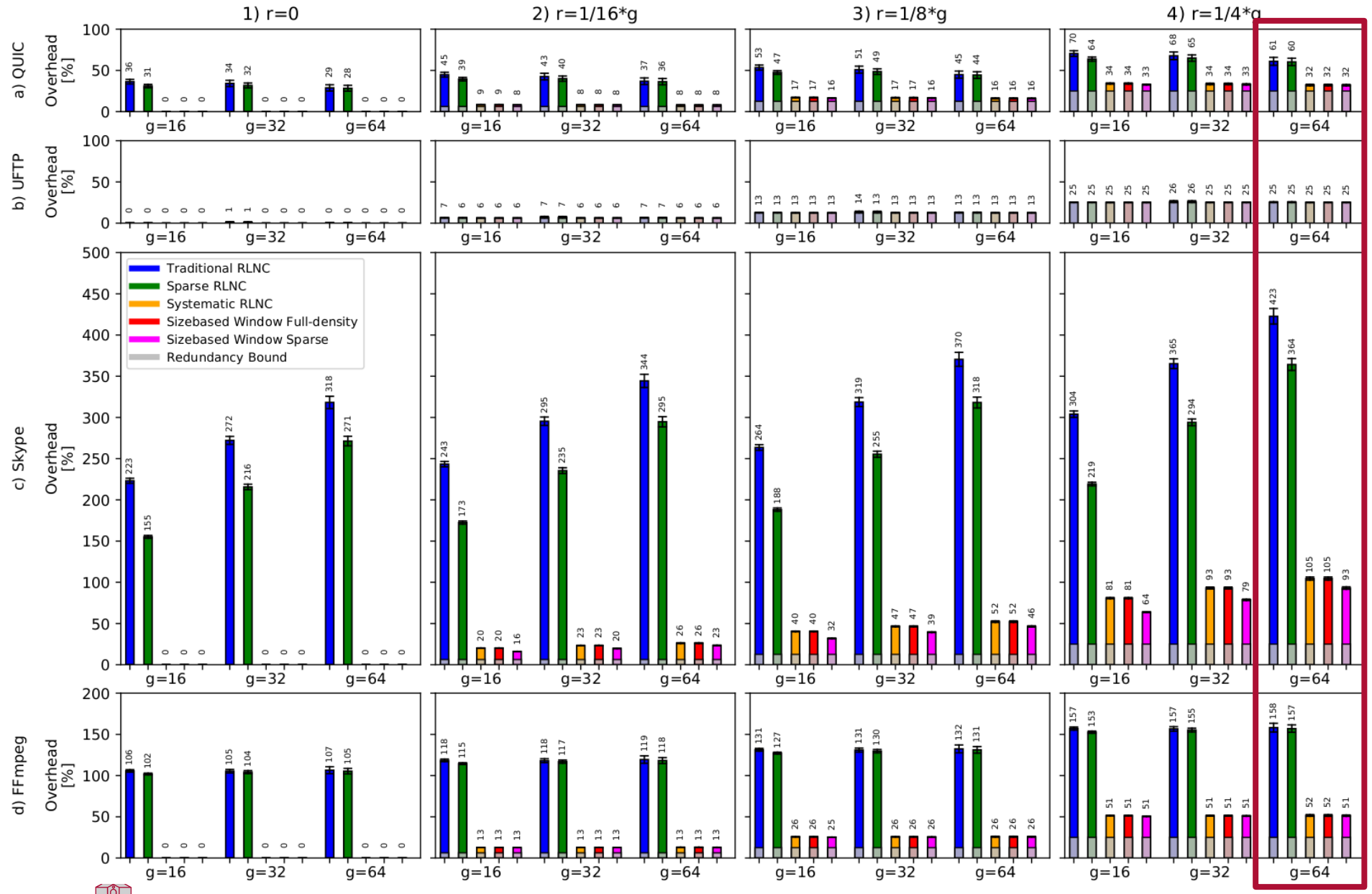
Traditional RLNC with pre-padding
Sparse RLNC with padding-on-demand
Systematic RLNC with pre-padding [paper]
Size-based Coding full density
Size-based Coding with sparsity



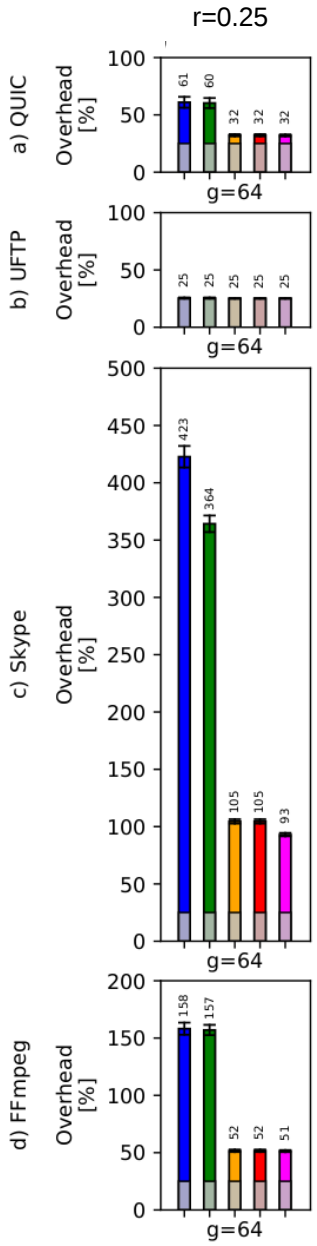
Evaluation Results



Evaluation Results



Evaluation Results



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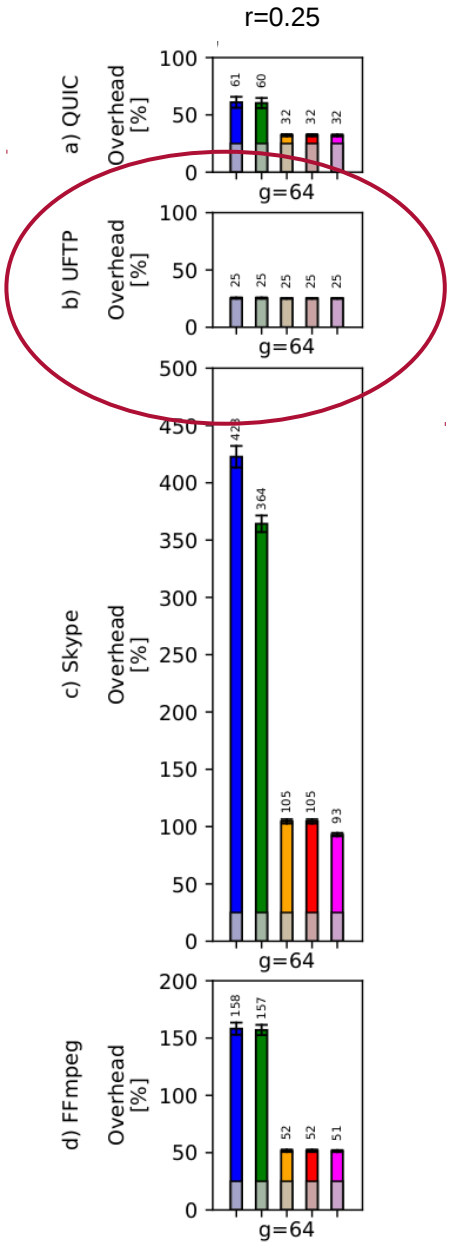
Evaluation Results



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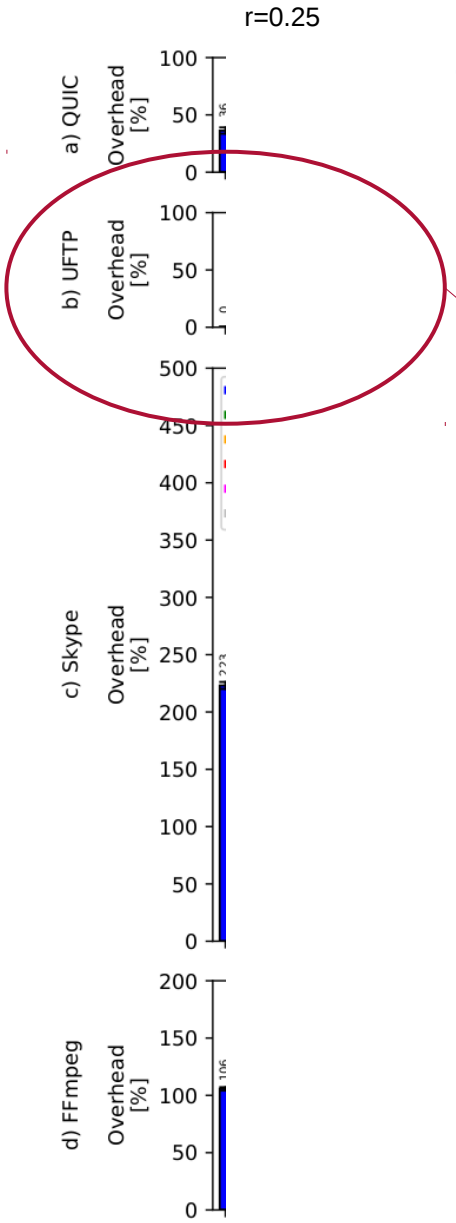
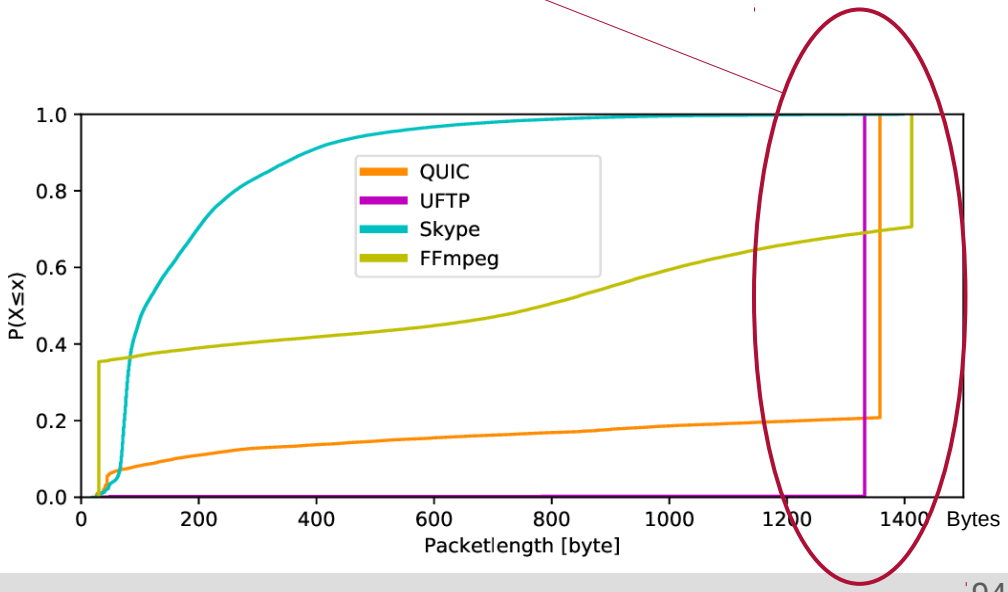


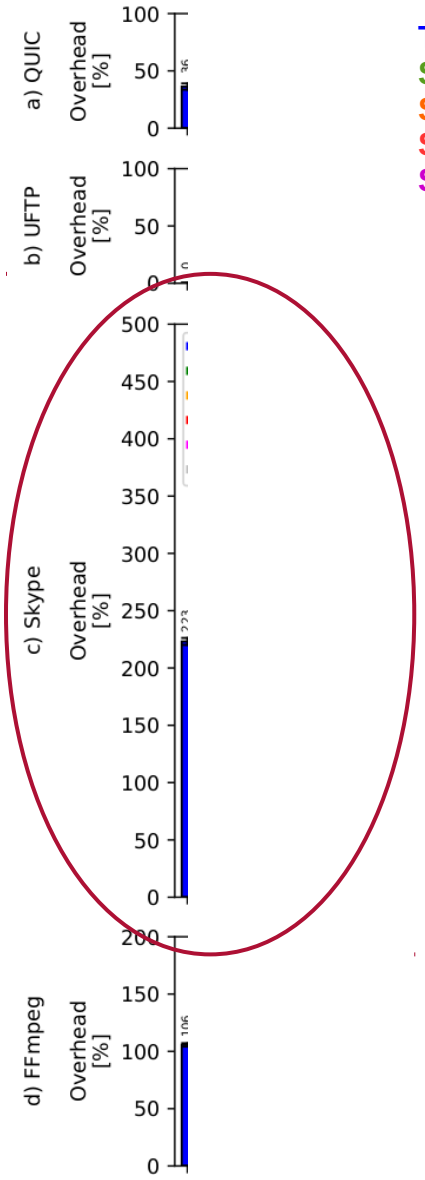
Traditional RLNC with pre-padding
Sparse RLNC with padding-on-demand
Systematic RLNC with pre-padding [paper]
Size-based Coding full density
Size-based Coding with sparsity

No packet length heterogeneity → no overhead

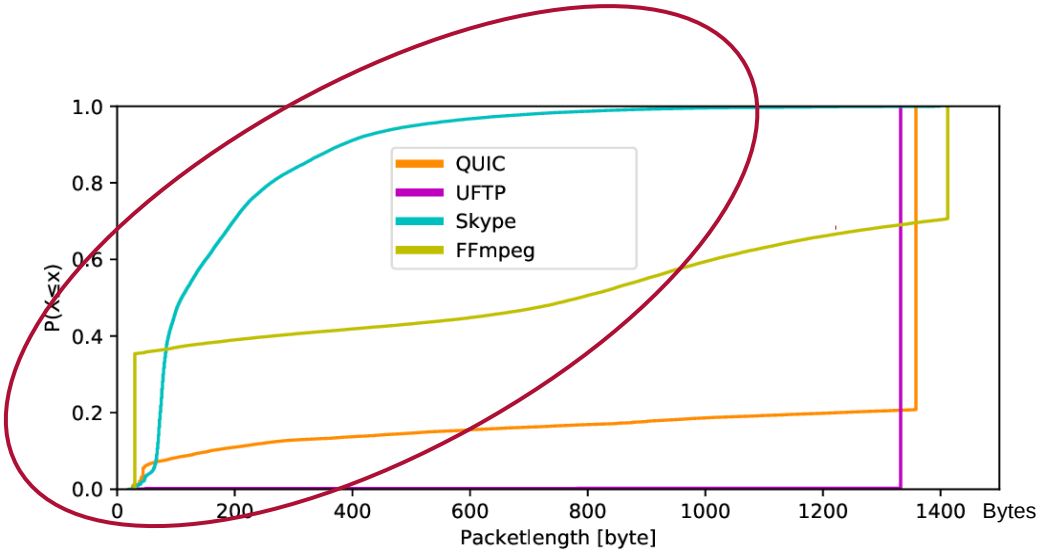


Evaluation Results

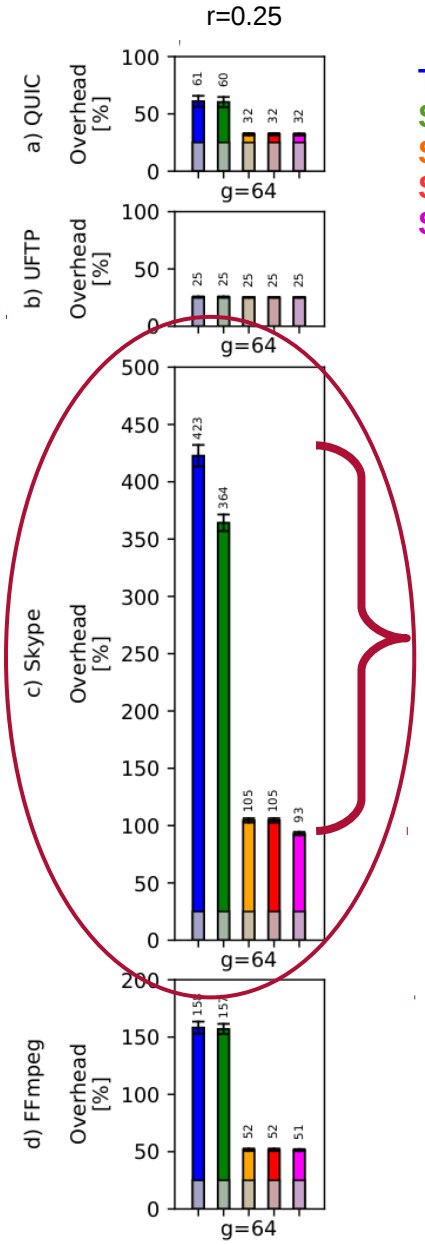
r=0.25



Traditional RLNC with pre-padding
Sparse RLNC with padding-on-demand
Systematic RLNC with pre-padding [paper]
Size-based Coding full density
Size-based Coding with sparsity

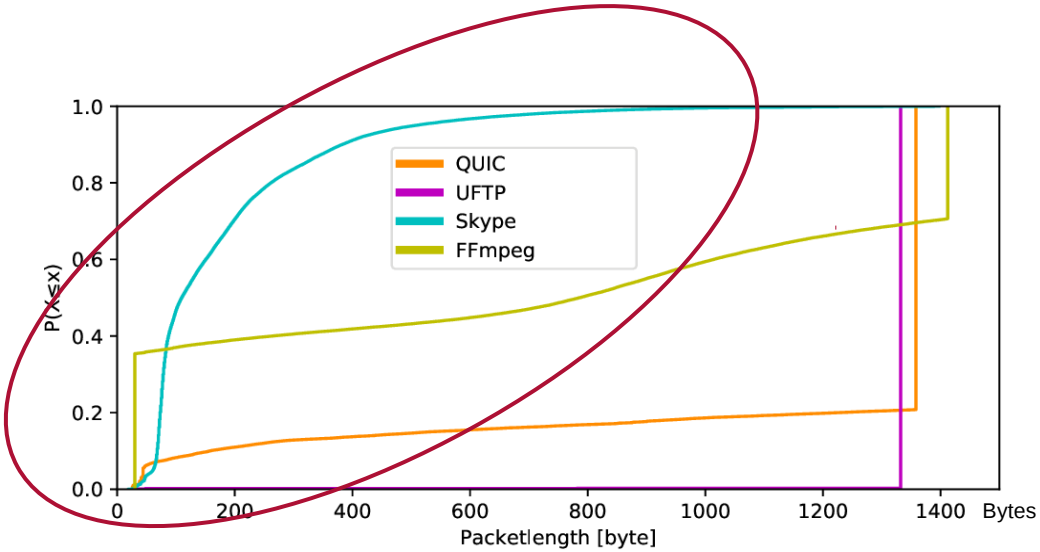


Evaluation Results

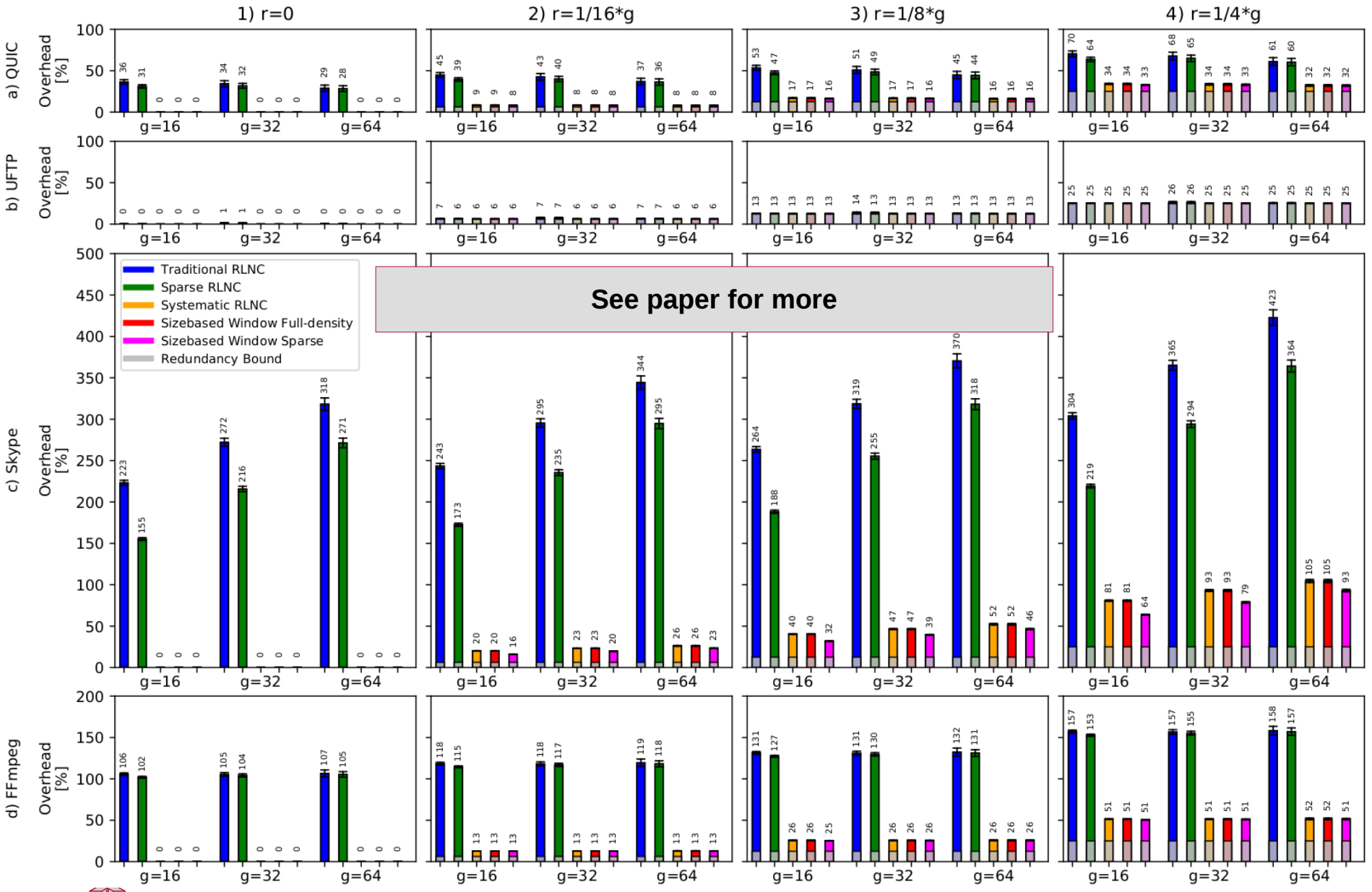


Traditional RLNC with pre-padding
Sparse RLNC with padding-on-demand
Systematic RLNC with pre-padding [paper]
Size-based Coding full density
Size-based Coding with sparsity

Overhead reductions of our approaches



Evaluation Results



Bridging the gap:

Challenges of deploying Network Coding in the real world

?!