DMTP: Deadline-aware Multipath Transport Protocol

Tony John
Networks and Distributed Systems Lab
OVGU Magdeburg

18.03.2025

Introduction

Modern Real-Time Applications Need:

- Strict latency
- High reliability
- Predictable performance

Targeted Use Cases:

Teleoperation	Telesurgery
Live Streaming	Online Gaming

Existing Approaches Fall Short:

E.g., dedicated networks and leased lines

- High cost
- Limited flexibility
- Complex management

SCION-based Approach:

Path-aware networking with multipath support

- Path selection controlled by end host
- Multiple heterogeneous paths
- Opens up possibility for dynamic optimization

➔ **Our Approach: Deadline-aware Multipath Transport Protocol (DMTP)**

DMTP leverages SCION's path awareness to ensure a reliable, timely data delivery

DMTP Overview

Primary Objective

Meet stringent latency requirements of real-time applications by ensuring reliable and timely data delivery through SCION's path awareness and multipath capabilities

Core Components

Optimal Path Selection

- Use optimal set of paths
- Distribute data across them

Smart Retransmission

- Selective retransmission
- Retransmit only when deadline can still be met

Adaptive FEC

- Combat random losses
- Reduce retransmissions
- Dynamic coding rate

Additional Features

- Multiple concurrent streams
- Priority-based handling

Optimal Path Selection

Input Metrics

- RTT (probes & metadata)
- Available Bandwidth (per path CC)
- Loss Rate (per path CC)
- Path Cost (metadata)

Optimizer

Output Decisions

- Selected Paths
- Bandwidth Distribution
- Retransmission/ACK Path

Heuristic Approach

- Fast decision
- Handle network dynamics
- Lower computational overhead

Advanced Solvers (LP / EMO)

- Guarantees near optimal solution
- Higher computational requirements
- Runs periodically

Optimization Objectives

- Meet application deadline requirements
- Ensure bandwidth requirements are met
- Minimize overall transmission cost

Smart Packet Retransmission

Retransmission Timing

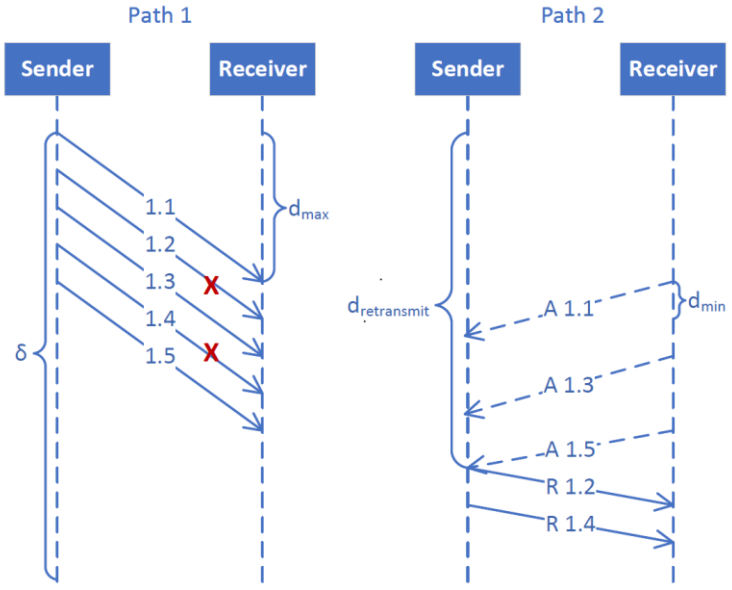
δ = Specified deadline	dmin = Retransmission path delay
dmax = Highest latency path delay	ACK time = dmax + dmin
Retransmit time = dmax + 2dmin	Must satisfy: dmax + 2dmin < δ

Retransmission Decision:

Timer set to dmax + dmin to allow for ACK collection

Key Principles

- Uses fastest among selected paths for retransmission
- Checks if enough fragments are acknowledged
- Considers FEC recovery capability
- Only retransmit if deadline can still be met



Adaptive Forward Error Correction (FEC)

Core Mechanism

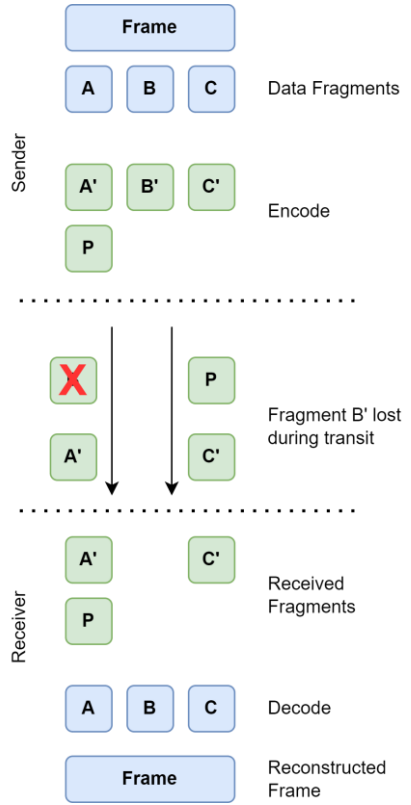
- Generates redundancy packets alongside data
- Enables packet reconstruction without retransmission
- Uses Reed-Solomon coding for multiple erasure support
- Adapts coding rate based on observed loss patterns

Path Distribution

- Redundancy fragments sent via different paths
- De-correlates losses between data and FEC

Benefits

- Reduces dependency on retransmissions
- Improves deadline adherence probability
- Minimizes latency impact of packet loss
- Efficient bandwidth utilization through adaptation



Adaptive Mechanism

Input Factors

- Moving window of previous losses
- Stream requirements

Adaptation Rules

- Coding rate adjusted per frame
- Max loss in window determines rate

Stream Priorities

Priority 0

Maximum Reliability

- 100% deadline achievement target
- Data duplication across paths
- For critical control signals

Priority 1

High Reliability

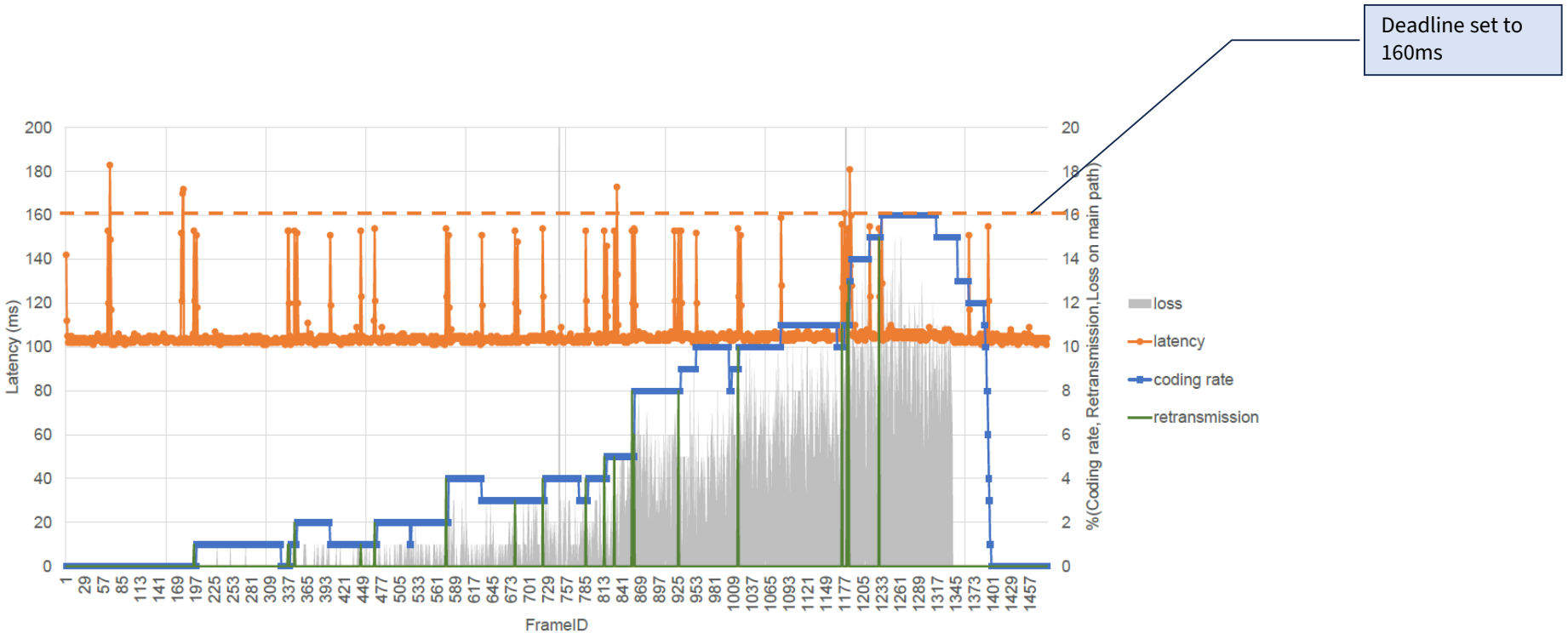
- 100% deadline achievement target
- Adaptive FEC/retransmission
- For main video streams

Priority 2

Best Effort

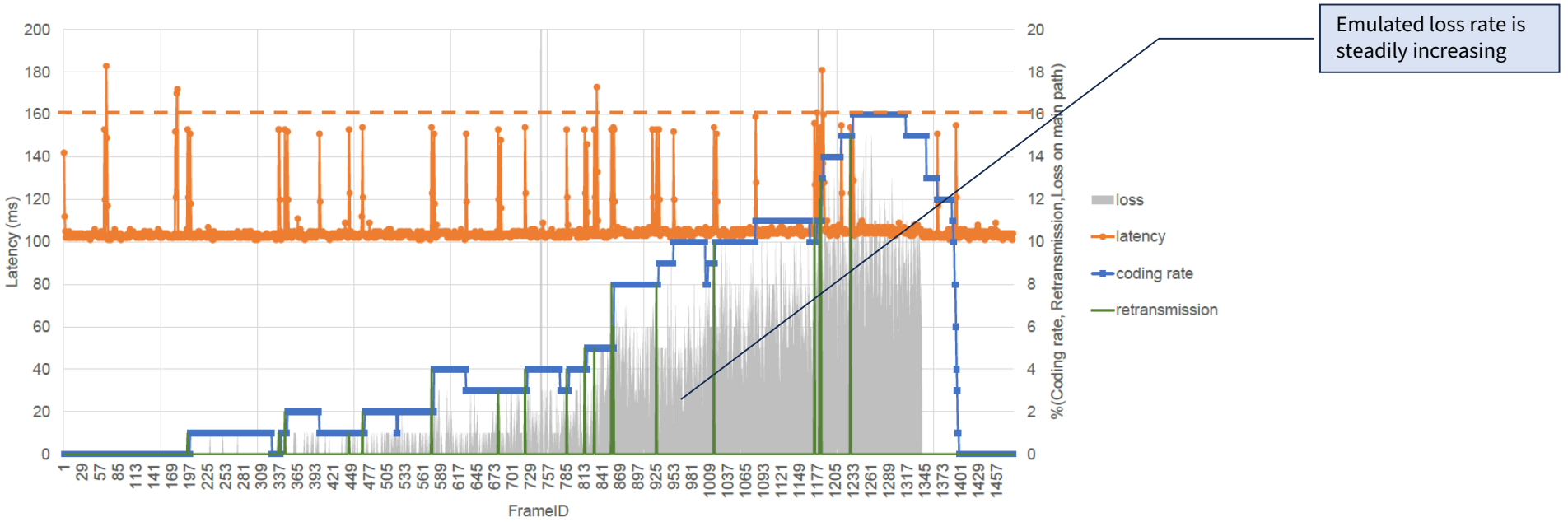
- Drop packets if capacity is limited
- Best effort delivery
- For auxiliary streams

Experiments and Results



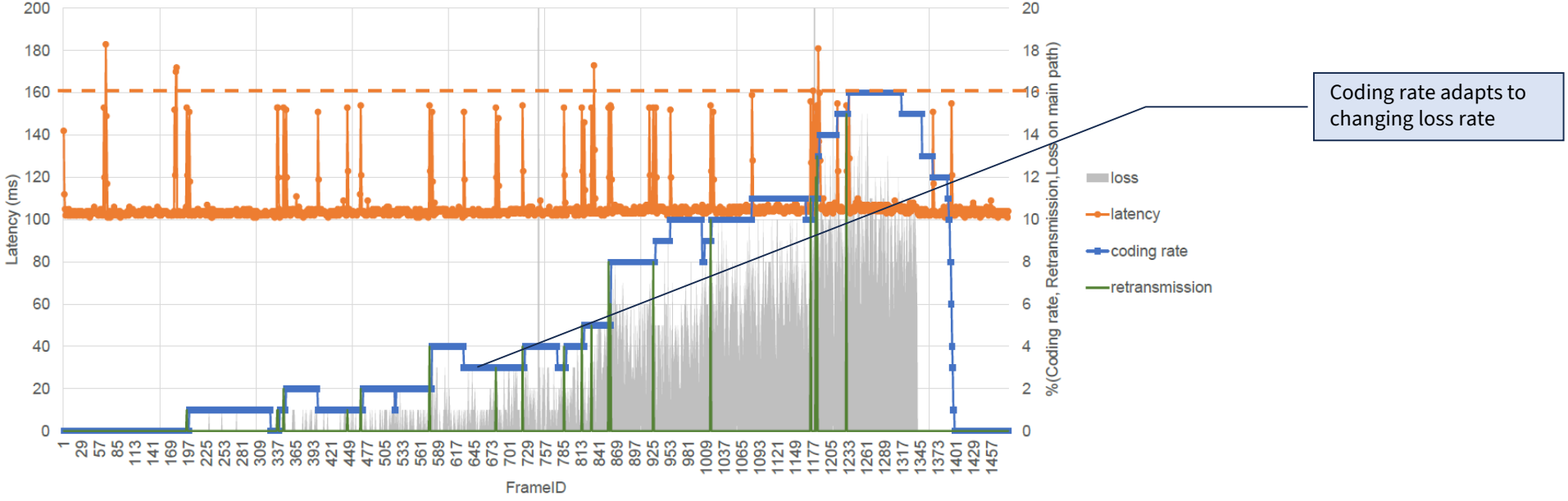
DMTP adapting to varying network conditions

Experiments and Results



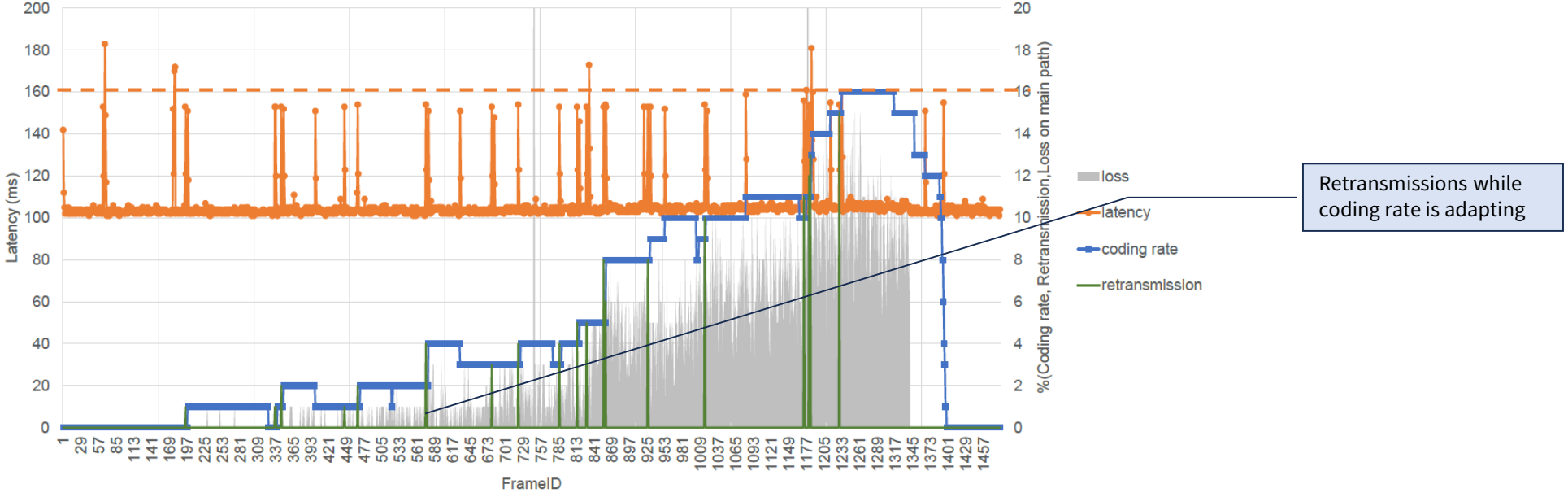
DMTP adapting to varying network conditions

Experiments and Results



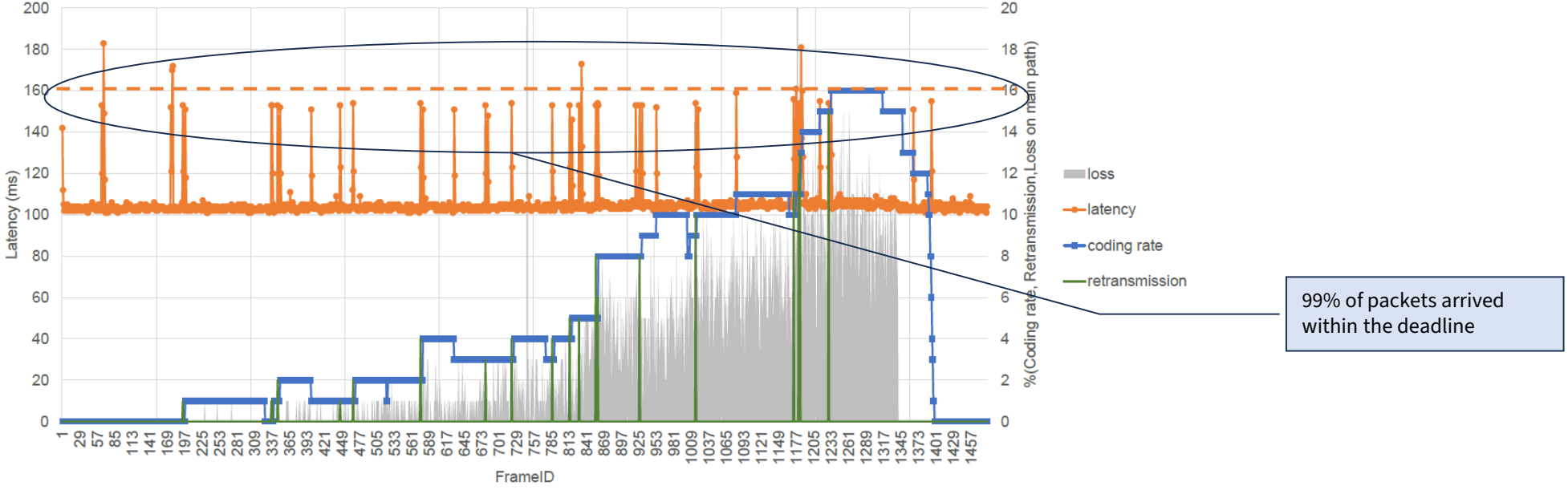
DMTP adapting to varying network conditions

Experiments and Results



DMTP adapting to varying network conditions

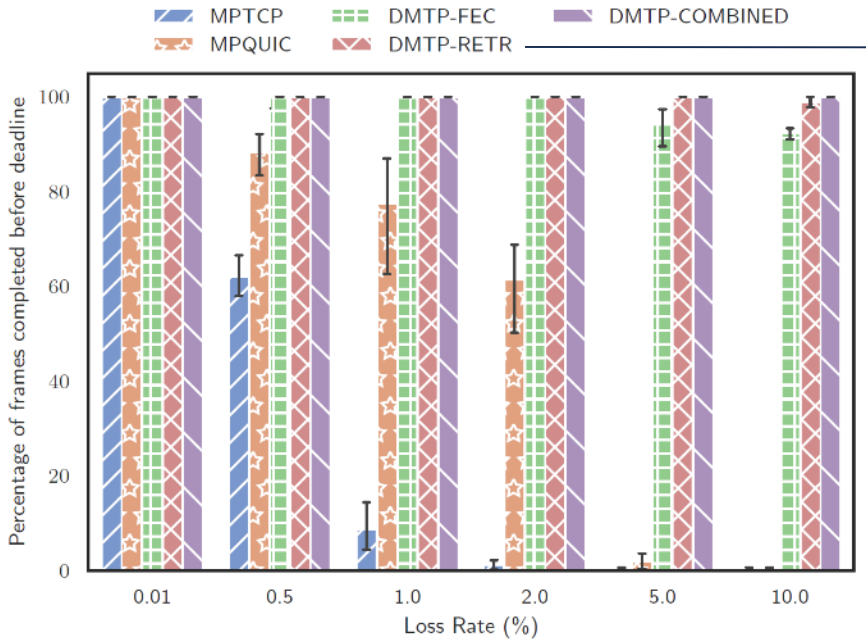
Experiments and Results



DMTP adapting to varying network conditions

Experiments and Results

DMTP-FEC: DMTP with Forward Error Correction
DMTP-RETR: DMTP with Smart Retransmission
DMTP-COMBINED: Combines FEC and Retransmission

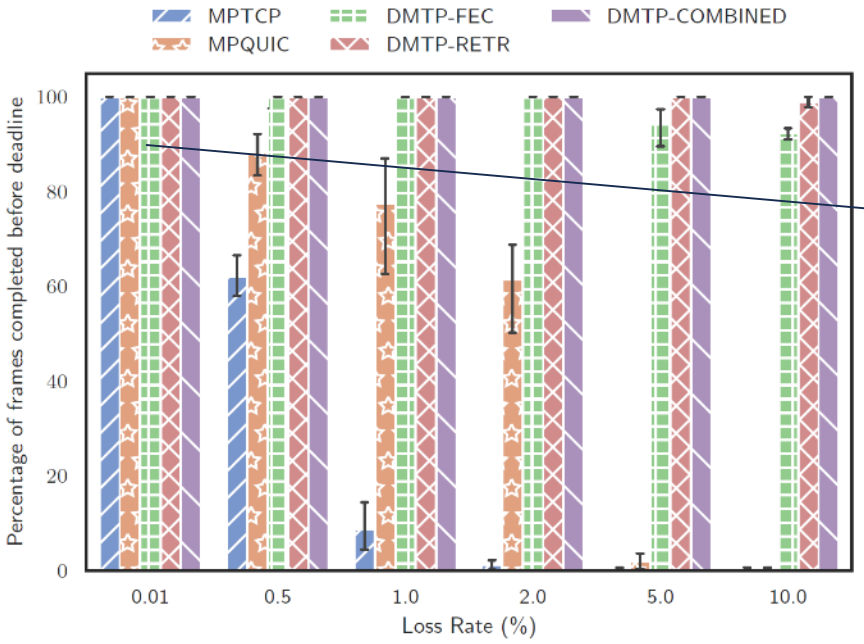


3 modes of DMTP compared with MPTCP and MPQUIC

Comparison with other Multipath transport protocols

Experiments and Results

DMTP-FEC: DMTP with Forward Error Correction
DMTP-RETR: DMTP with Smart Retransmission
DMTP-COMBINED: Combines FEC and Retransmission

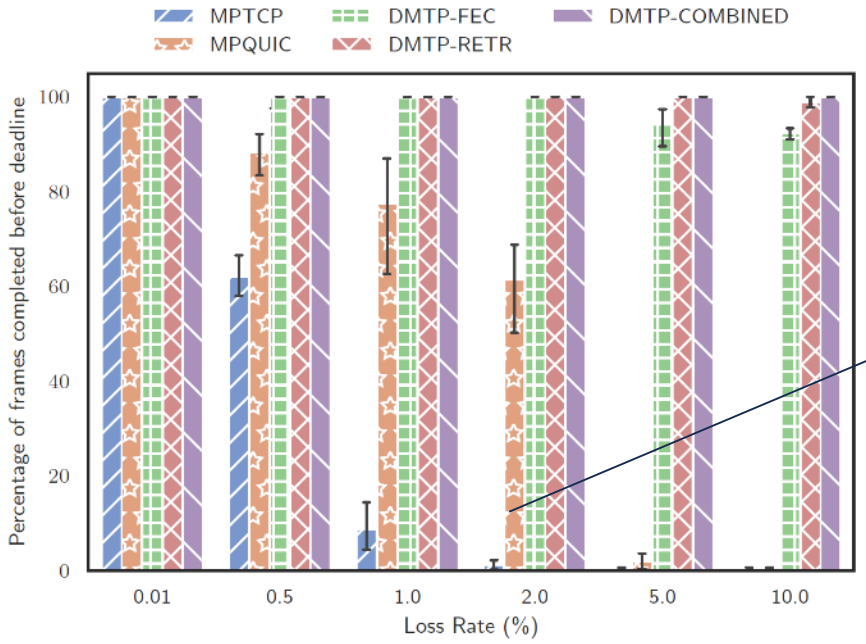


All approaches work well when loss rate is very low

Comparison with other Multipath transport protocols

Experiments and Results

DMTP-FEC: DMTP with Forward Error Correction
DMTP-RETR: DMTP with Smart Retransmission
DMTP-COMBINED: Combines FEC and Retransmission

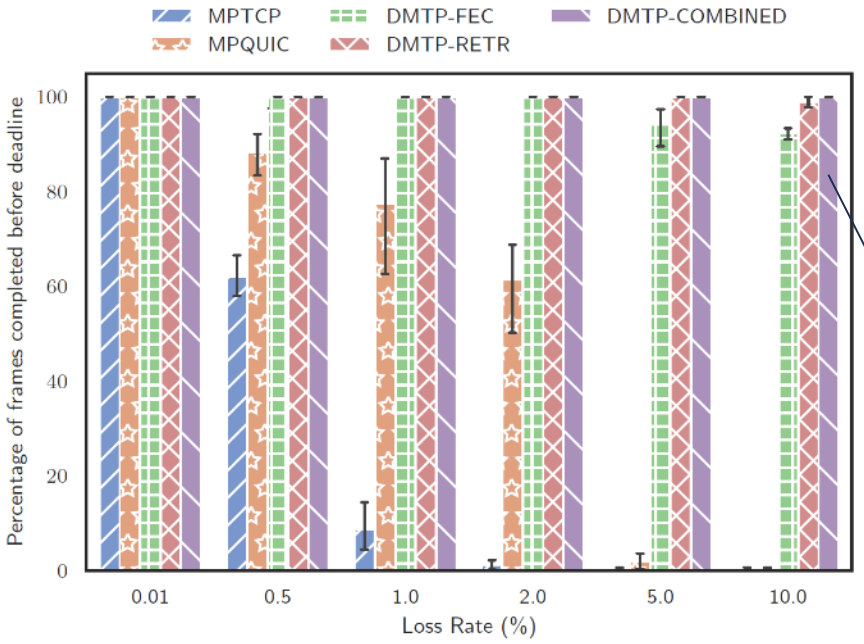


MPTCP/MPQUIC struggle to deliver packets within deadline when loss rate increases

Comparison with other Multipath transport protocols

Experiments and Results

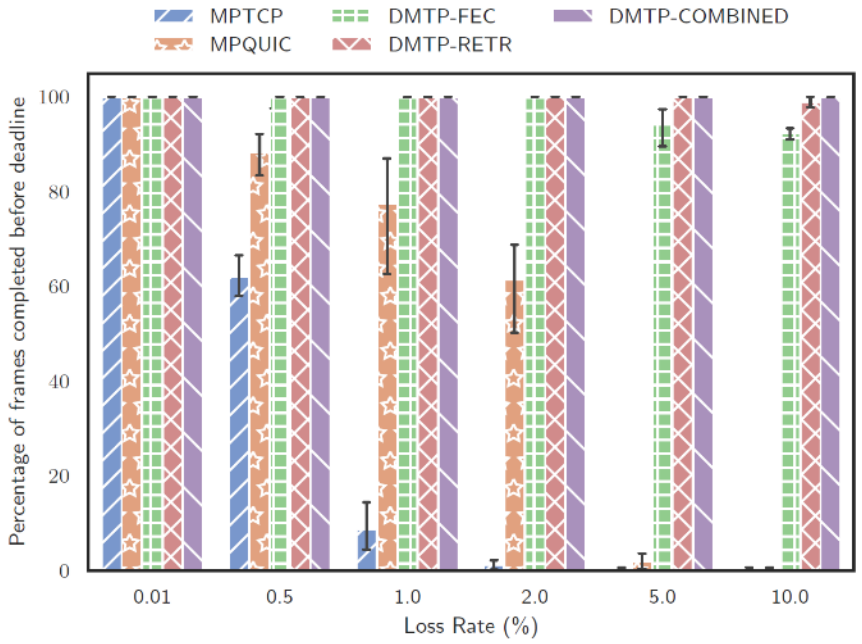
DMTP-FEC: DMTP with Forward Error Correction
DMTP-RETR: DMTP with Smart Retransmission
DMTP-COMBINED: Combines FEC and Retransmission



Comparison with other Multipath transport protocols

DMTP-Combined delivers 99% of packets within deadline at 10% loss rate

Experiments and Results



Comparison with other Multipath transport protocols

Design Focus Difference

MPTCP/MPQUIC optimize for high throughput and connection management, while DMTP prioritizes deadline guarantees and reliability

Performance Trade-off

DMTP achieves better reliability through higher resource usage per packet

➔ justified for latency-critical applications

Field Tests and Results

- DMTP was tested in the field in collaboration with the Robotics Systems Lab at ETH Zurich[1]
- A real excavator was remotely operated from 30km away

Test Streams

Priority 0

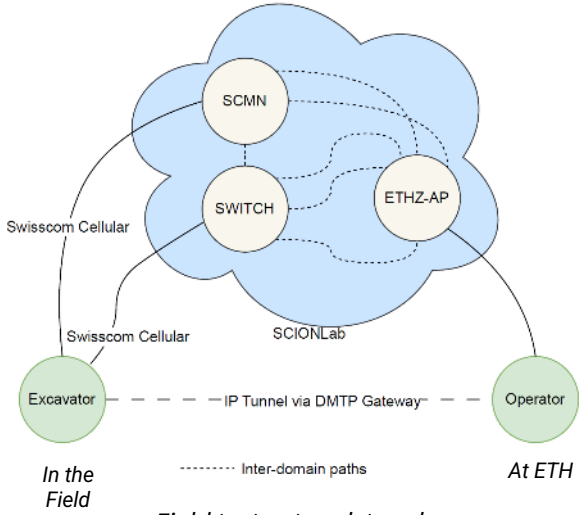
- Telemetry data
- Control signal

Priority 1

- Main camera feed
- Primary visual feedback

Priority 2

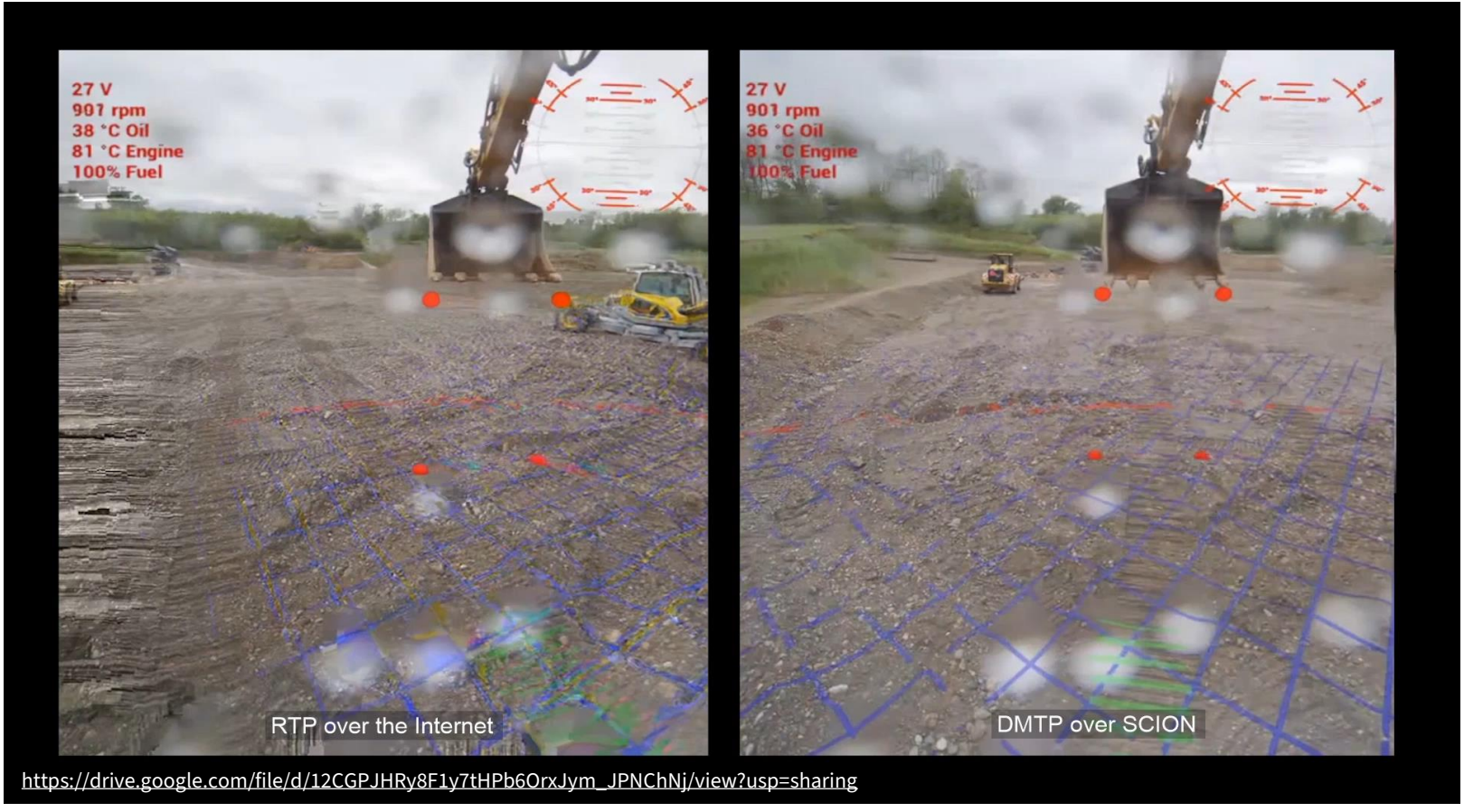
- 3 auxillary cameras



Field test network topology

1. https://rsl.ethz.ch/partnership/spinoff/gravisrobotics.html

Field Tests and Results



https://drive.google.com/file/d/12CGPJHRy8F1y7tHPb6OrxJym_JPNChNj/view?usp=sharing

Ongoing Standardization Effort: DMTP Extension to QUIC-Multipath

Internet Draft Status

- Submitted draft-tjohn-quic-multipath-dmtp-00
- Proposes minimal extensions to QUIC for deadline-aware streams – building on existing multipath capabilities
- Consideration for experimental track

Feedback by the QUIC WG

1. Timestamp approach: Align with draft-huitema-quic-ts-08 for one-way delay measurements
2. Protocol vs. API discussion: Why protocol-level extensions?
    - Receiver coordination
    - Interoperability for FEC mechanisms
    - Consistent implementation across stacks

Key Components

- Transport Parameter: `enable_deadline_aware_streams` for negotiation
- DEADLINE_CONTROL Frame: Signals per stream deadlines
- Partial reliability: Only retransmit when deadline still achievable
- Optional Adaptive FEC: Reduce retransmission overhead due to random losses
- Map paths available from PAN to different path identifiers in QUIC-MULTIPATH

Next Steps

- Revise draft based on QUIC WG feedback
- Make extension composable with either QUIC or QUIC-MULTIPATH
- Collect performance data with prototype implementation

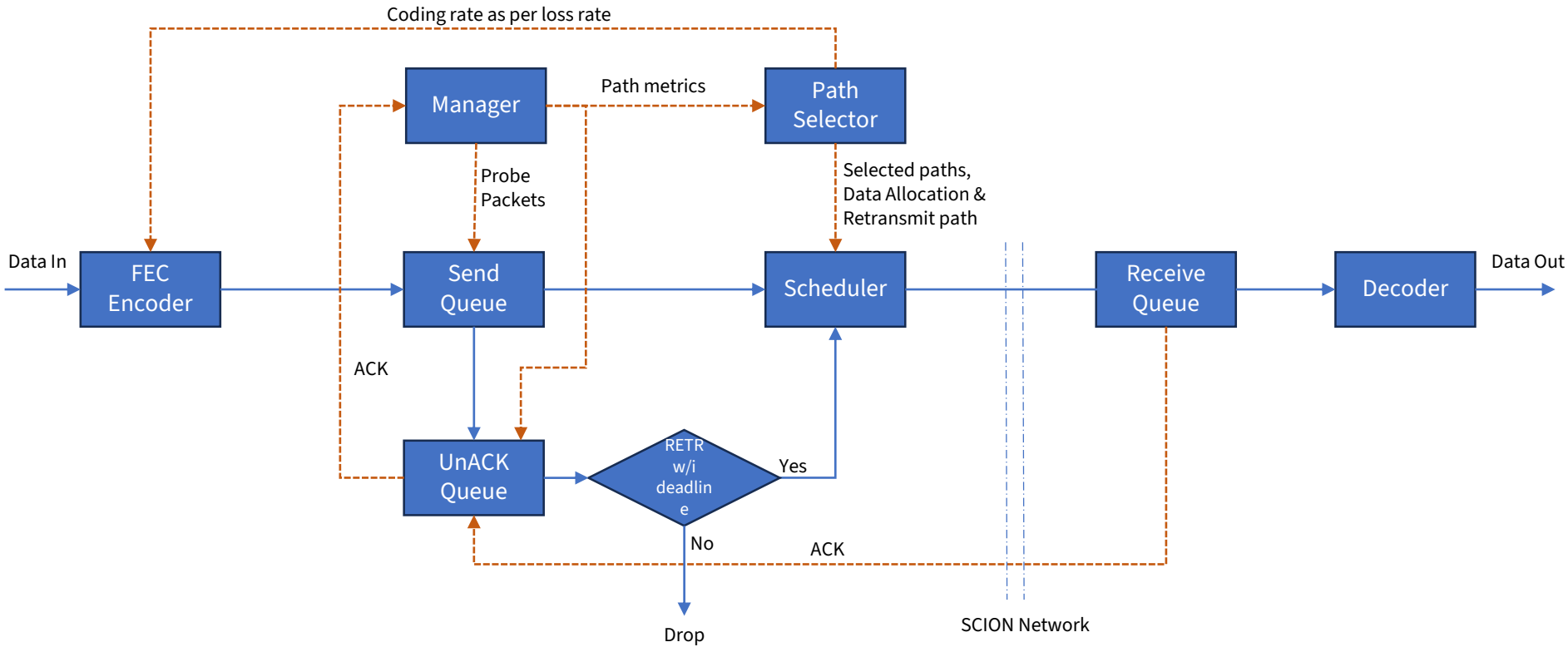
Thank you!

References

- John, T., Riechard, T.-F. (2025, March): Deadline Aware Streams in MP-QUIC. https://datatracker.ietf.org/doc/draft-tjohn-quic-multipath-dmtp/
- John, T., Perrig, A., & Hausheer, D. (2023, June). DMTP: Deadline-aware Multipath Transport Protocol. In 2023 IFIP Networking Conference (pp. 1-9)
- Labutkina, A., Selezneva, A., John, T., & Hausheer, D. (2024, May). Multiobjective Path Optimization for Deadline-aware Multipath over SCION. In 2024 IEEE International Conference on Machine Learning for Communication and Networking (ICMLCN) (pp. 56-62)

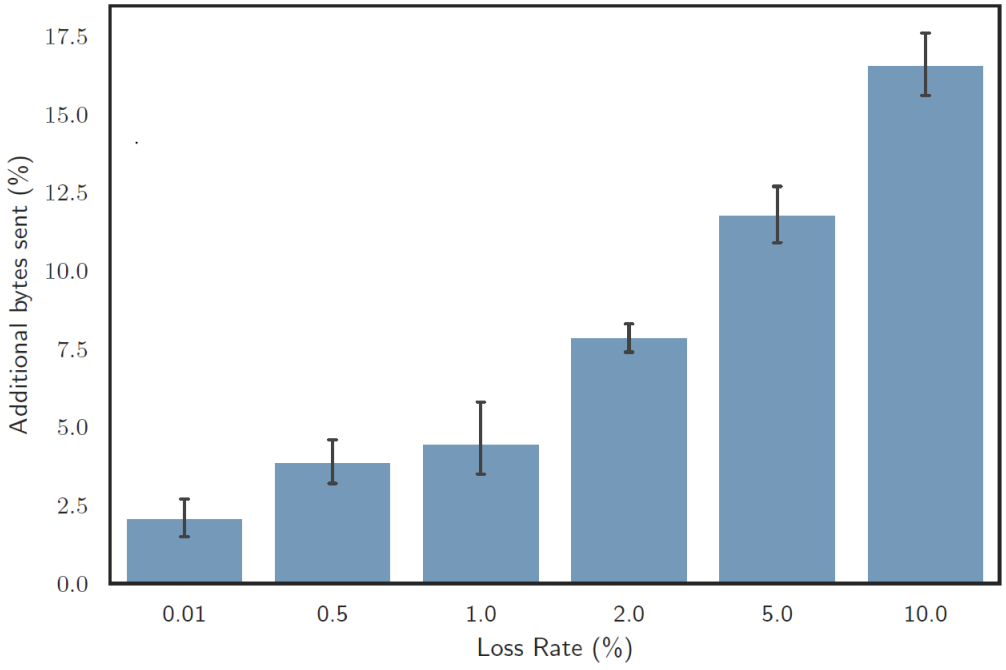
Backup Slides

DMTP Flow

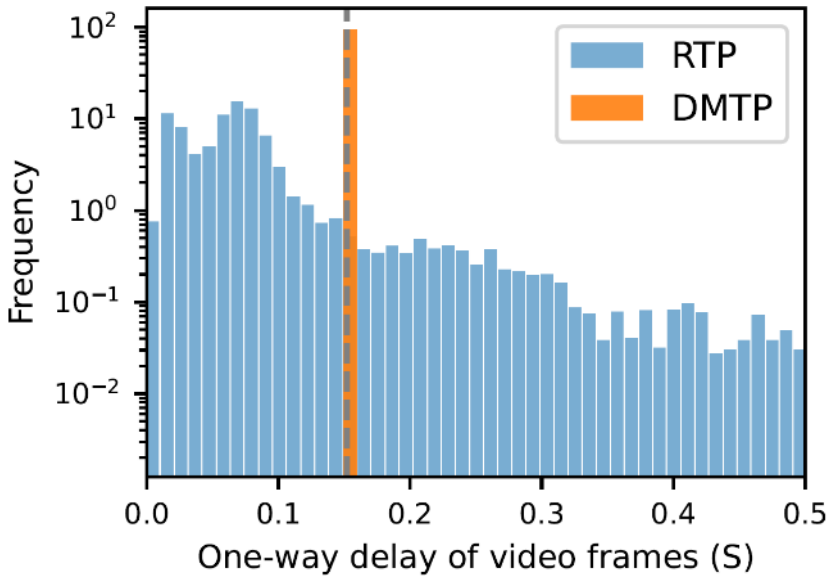

Coding rate as per loss rate
Manager
Path metrics
Path Selector
Probe Packets
Selected paths, Data Allocation & Retransmit path
Data In
FEC Encoder
Send Queue
Scheduler
Receive Queue
Decoder
Data Out
ACK
UnACK Queue
RETR w/i deadline
Yes
No
ACK
Drop
SCION Network

Evaluation – Overhead of DMTP

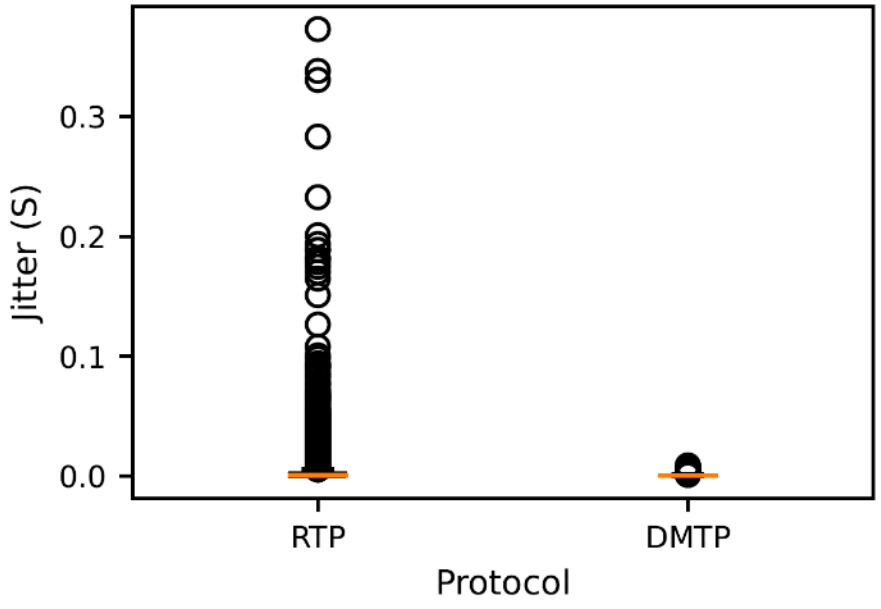
- Overhead includes additional bytes sent as packet headers, retransmissions, and redundancy fragments
- While overhead was generated, DMTP consistently maintained the deadlines, even under high loss rates



DMTP – Field Tests and Results (cont'd)



Distribution of one-way delay of main camera frames



Observed jitter on the main camera frames