X-Lap: A Systems Approach for Cross-Layer Profiling and Latency Analysis for Cyber-Physical Networks
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Cyber-Physical Networks (CPNs)
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## Existing Solutions

| Single-Host Evaluation Tools | Network Evaluation Tools |
|-----------------------------|--------------------------|
| ▶ Local evaluation          | ▶ Network protocol evaluation |
| ▶ Network-oblivious         | ▶ Abstract from host-related delays |
## Existing Solutions

### Single-Host Evaluation Tools
- Local evaluation
- Network-oblivious

### Network Evaluation Tools
- Network protocol evaluation
- Abstract from host-related delays

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**Need for Cross-Layer-Analysis of communication stacks**
Outline

Introduction

X-LAP

PRRT

Evaluation

Conclusion
Outline

Introduction

X-LAP

PRRT

Evaluation

Conclusion
Introduction

- Packet creation
- Error correction
- ...

- Inter-process communication (IPC)
- Resource management
- ...

- Transmission delay
- Propagation delay
- ...

X-LAP | Operating system
X-LAP | Transport protocol
X-LAP | Application
X-LAP | Channel
## X-LAP | Architecture

### Run-time evaluation
- Timestamping functions
- ⇒ Timestamps
- C code

### Off-line analysis
- Data analysis
- ⇒ Latency and jitter
- Python code
### X-Lap | Architecture

#### Run-time evaluation
- Timestamping functions
- Timestamps
- C code

#### Off-line analysis
- Data analysis
- Latency and jitter
- Python code

- Trace every packet
- Minimize run-time interference
- Embedded into protocol source code
Run-time evaluation

- Timestamping functions
  - Timestamps
- C code

Off-line analysis

- Data analysis
  - Latency and jitter
- Python code

Collect traces
Combine trace data

*.csv
Run-time evaluation

- Timestamping functions
- \( \Rightarrow \) Timestamps
- C code

Off-line analysis

- Data analysis
- \( \Rightarrow \) Latency and jitter
- Python code

*.csv

- Single-packet traces
- Jitter amongst packets
- Outlier analysis
- Correlation analysis
Outline

Introduction

X-LAP

PRRT

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Conclusion
### Predictably Reliable Real-time Transport (PRRT)

| Protocol | Features |
|----------|----------|
| **UDP**  | - Data integrity checks  
          | - No timeliness guarantees |
| **TCP**  | - Error control  
          | - No timeliness guarantees |

Not suitable for reliable real-time networks.
Predictably Reliable Real-time Transport (PRRT)

**UDP**
- Data integrity checks
- No timeliness guarantees

**TCP**
- Error control
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Not suitable for reliable real-time networks
Predictably Reliable Real-time Transport (PRRT)

UDP
- Data integrity checks
- No timeliness guarantees

TCP
- Error control
- No timeliness guarantees

PRRT
- Error correction
- Latency-awareness

⚠️ Not suitable for reliable real-time networks
Automated Repeat reQuest (ARQ)

Forward Error Correction (FEC)
Automated Repeat reQuest (ARQ)

Forward Error Correction (FEC)

Hybrid Error Correction (HEC)
Automated Repeat reQuest (ARQ)

Forward Error Correction (FEC)

Hybrid Error Correction (HEC)

Application Constraints

Channel State Information (CSI)
PRRT | Error Control and Timeliness

- **Automated Repeat reQuest (ARQ)**
- **Forward Error Correction (FEC)**
- **Hybrid Error Correction (HEC)**
- **Adaptive HEC (AHEC)**
- **Application Constraints**
- **Run-time CSI**

Channel State Information (CSI)
Automated Repeat reQuest (ARQ)
Forward Error Correction (FEC)
Hybrid Error Correction (HEC)
Adaptive HEC (AHEC)
Application Constraints
System Information
Run-time CSI
Automated Repeat reQuest (ARQ)  
Forward Error Correction (FEC)  
Application Constraints  
System Information  
Adaptive HEC (AHEC)  
Jitter  
Run-time CSI
Benefits from X-LAP

- Obtain system information
- Analyse jitter

Goals: Latency and jitter ...

- ... avoidance
  → Eliminate causes of latency and jitter
- ... hiding
  → Preparatory/Clean-up tasks
  → Optimise resource management
- ... tolerance
  → Parameters for AHEC
Evaluation focus

- PRRT
- Interaction with OS

Future work

- Application delays
- Network transmission time
PRRT | Results: Packet Trace

The graph shows the breakdown of time spent on various packet transmission stages:
- **Feedback**: 80us
- **ReceiverIPC**: 80us
- **HandlePacket**: 60us
- **ReceiverTotal**: 80us
- **LinkTransmit**: 60us
- **PrrotTransmit**: 60us
- **SenderEnqueued**: 20us
- **Enqueue**: 20us
- **SenderIPC**: 20us
- **Submit**: 20us
- **Send**: 20us
- **SenderTotal**: 80us
- **EndToEnd**: 160us

The x-axis represents time in microseconds (us), ranging from 0 to 160.
PRRT | Results: Trace Jitter
PRRT | Results: Outliers

![Bar chart showing frequency of various events]

- ReceiverIPC
- HandlePacket
- SenderEnqueued
- PrrtTransmit
- SenderIPC
- LinkTransmit
- Feedback
- Decoding
- Enqueue
- Send
- Submit

Frequency
PRRT | Results: Correlation SenderTotal

![Graph showing correlation between SenderTotal and EndToEnd]
Outline

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PRRT

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**Conclusion**

**X-LAP**
- Cross-layer, inter-host timing analysis tool
- Evaluation of real-time network protocols

**PRRT Analysis**

|                | Sender          | Receiver         | Network-related          |
|----------------|-----------------|------------------|--------------------------|
| **Latency**    | PrrtTransmit    | SendFeedback     | LinkTransmit             |
| **Jitter**     | SenderEnqueue   | ReceiverIPC      | LinkTransmit             |

Source Code available at: [http://xlap.larn.systems](http://xlap.larn.systems)


**X-LAP**

- Cross-layer, inter-host timing analysis tool
- Evaluation of real-time network protocols

**PRRT Analysis**

|               | Sender     | Receiver   | Network-related |
|---------------|------------|------------|-----------------|
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Thank you for your attention. Questions?