Transparent TSN for Agnostic End-hosts via P4-based Traffic Characterization at Switches

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Motivation

Challenges in Mission-Critical Systems

Background

Standard Ethernet is insufficient

Standard Ethernet

Best-effort packet delivery

No inherent latency guarantees

Optimized for general-purpose

Problem:

Standard Ethernet cannot ….

- Satisfy MCS timing and bandwidth constraints
- Inherently solve its packet loss
- Offer security for resource constrained devices

Time-Sensitive Networking (TSN)

Deterministic delivery of data

Traffic-shaping and QoS

Low-latency and high bandwidth

Problem:

TSN….

- Is built upon several standards
- Networks have compatibility issues
- Requires careful bandwidth allocation
- Needs to overcome security implications

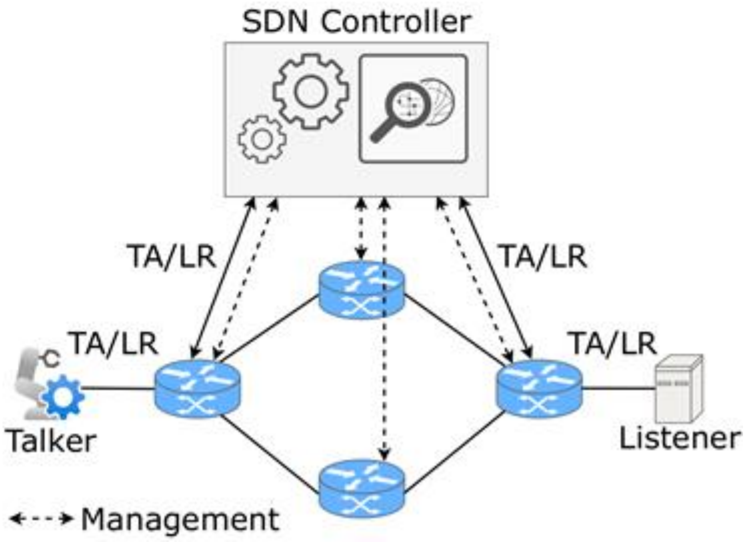
Problem statement and Research Question

End-hosts need to know **how** to schedule their transmission (according to the network's timing and rules)

= TSN-Awareness

Research Question:

How can we eliminate end-host dependencies in TSN and facilitate traffic flow management?



Centralized Control via SDN

- \+ Simplified resource management
- \+ Facilitates dynamic traffic control
- \- Latency concerns
- \- Potential bottleneck as network grows

Approach

Transparent TSN

Shift TSN responsibilities from end-hosts to network infrastructure

- Traffic classification
- Traffic identification
- Network management interaction

~~SDN Controller~~

~~End-hosts~~

Switches

+ Lower complexity
+ Lower network management overhead
+ Reduced latency
+ More scalable and robust network
+ Anomaly detection

Approach

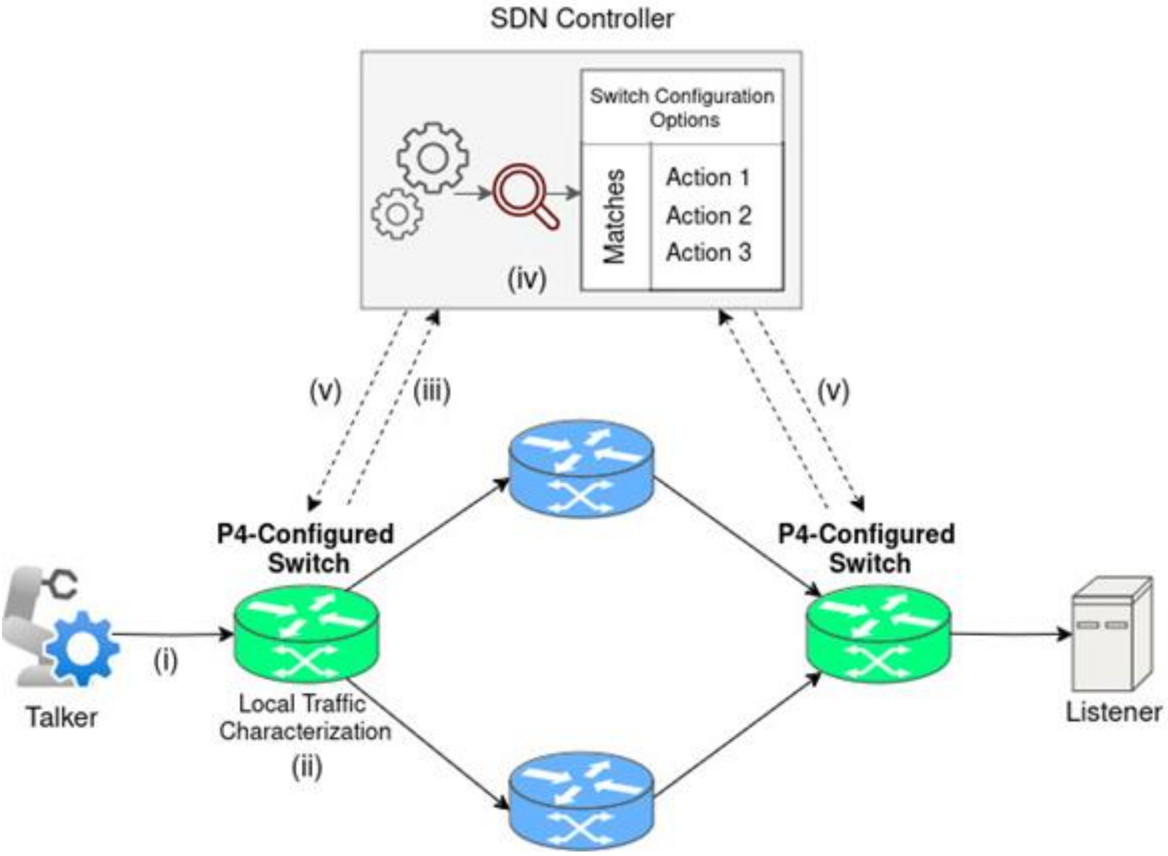
Decentralized In-Switch Monitoring

Edge switches:

- Disassemble packets
- Extract traffic characteristics
- Determine traffic type locally

$$R(k) = \frac{\sum_{t=1}^{N-k}(x_t - \bar{x})(x_{t+k} - \bar{x})}{\sum_{t=1}^{N}(x_t - \bar{x})^2} \quad \forall N, \bar{x}, k \in \mathbb{N}$$

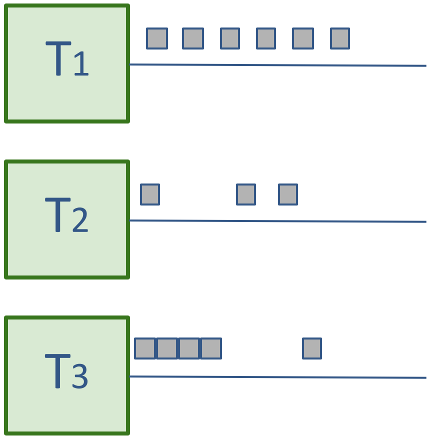
$R(k)$: Autocorrelation coefficient at lag k.
N : Total number of frame inter-arrival times.
$x_t \geq 0$: Inter-arrival time of the t-th frame.
$\bar{x}$: Mean inter-arrival time.
k : Lag, inter-arrival times displacement.



Implementation

System Setup

- Network setup in Mininet 2.3.1ba
- Simple Switch Behavior Model v2 (BMv2)
- Switch programming using P4
- Multiple scripts for traffic generation
- Calculate the autocorrelation to classify traffic



periodic

sporadic

burst

Implementation

Traffic Characterization

Problem No. 1:

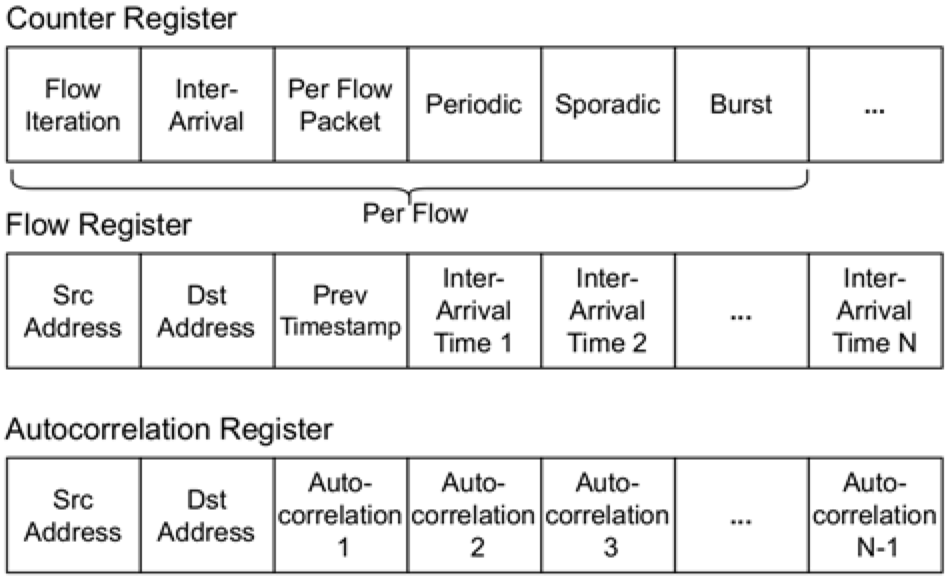
P4 does **not maintain state** between packet processing operations.

Problem No. 2:

Which algorithm to pick for traffic characteristics when P4 can only use **limited arithmetic operations?**

Problem No. 3:

How much traffic should be monitored / stored for classification?



Counter Register

Flow Iteration	Inter-Arrival	Per Flow Packet	Periodic	Sporadic	Burst	...

Per Flow

Flow Register

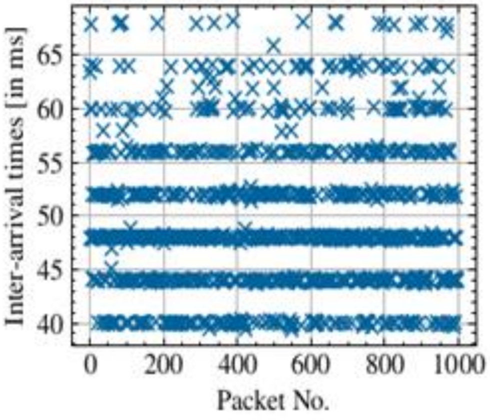
Src Address	Dst Address	Prev Timestamp	Inter-Arrival Time 1	Inter-Arrival Time 2	...	Inter-Arrival Time N

Autocorrelation Register

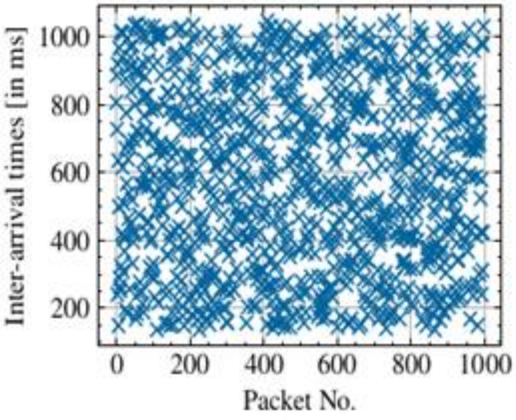
Src Address	Dst Address	Auto-correlation 1	Auto-correlation 2	Auto-correlation 3	...	Auto-correlation N-1

Results

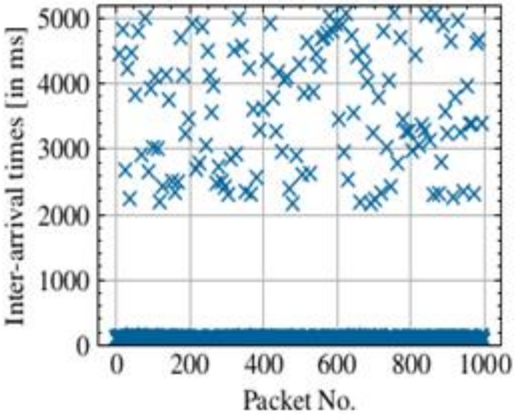
Traffic Characterization with P4 on the Switch



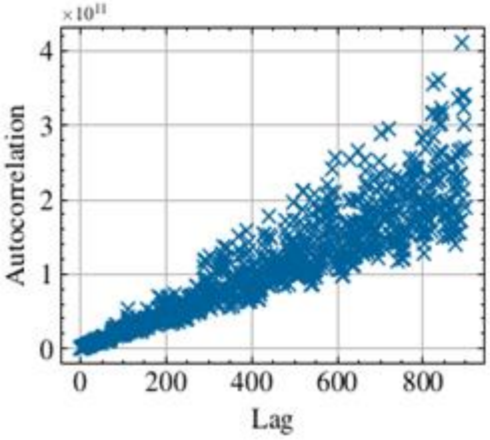
(a) periodic



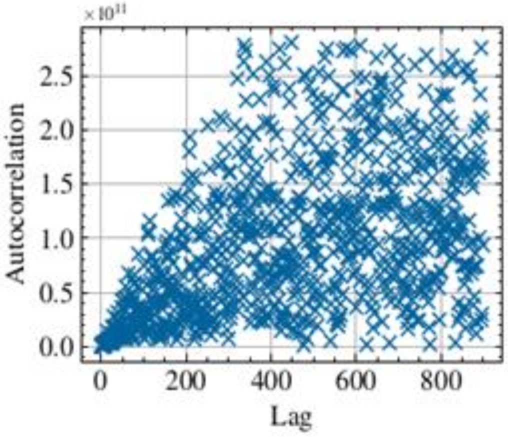
(b) sporadic



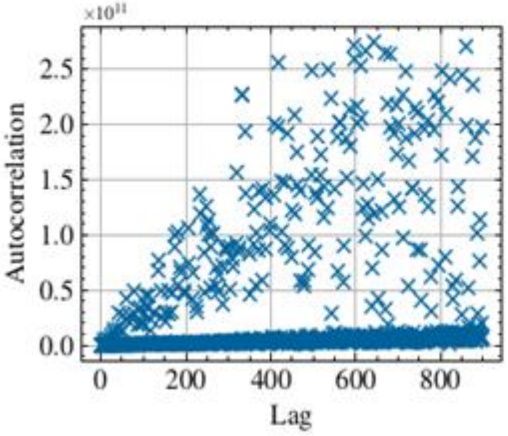
(c) burst



(a) periodic



(b) sporadic



(c) burst

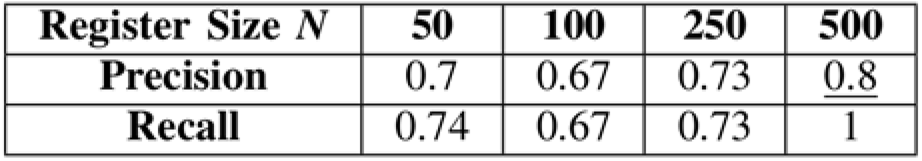
Evaluation

Traffic Characterization with P4 on the Switch

Sliding Windows Evaluation:

Register Size N = **500 / 200 / 100 / 50**

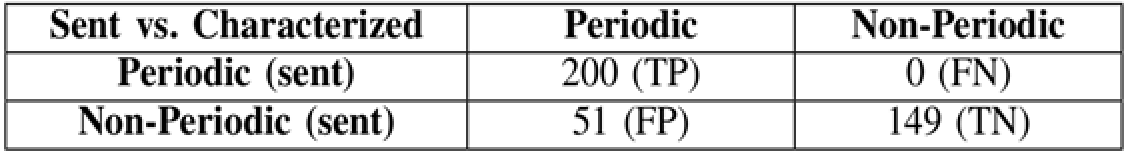
Precision and Recall for varying register sizes



Register Size N	**50**	**100**	**250**	**500**
Precision	0.7	0.67	0.73	0.8
Recall	0.74	0.67	0.73	1

Confusion Matrix

200 periodic and 200 non-periodic traffic flows



Sent vs. Characterized	**Periodic**	**Non-Periodic**
Periodic (sent)	200 (TP)	0 (FN)
Non-Periodic (sent)	51 (FP)	149 (TN)

Forwarding Latency

tshark to capture ingress and egress ports on the switch: **0.22 ms** per packet

Conclusion

Our approach:

- Reduces communication overhead / network load
- Reduces latency compared to traditional / SDN approaches
- Remove end-host dependencies for reservation requests
- In-Switch anomaly detection for traffic classes

Network participants reap the benefits of TSN

“Costs” only 0.2 ms per packet

Towards autonomous switches for a flexible network

Facilitates the switch from legacy systems to time-sensitive networks

We taught resource-constrained devices (switches) to characterize time-sensitive traffic locally!

Thank you!

Time for questions

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