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Anomaly Detection in Real-Time Networks Using Asynchronous Traffic Shaping

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Outline

I. Introduction
II. Detecting Anomalies with Asynchronous Traffic Shaping
III. Benchmarking Detection Performance
IV. Conclusion & Outlook

Real-Time Networks

In-vehicle communication includes safety-critical functions

- Reliability and predictability is essential
- Traditional Ethernet cannot meet these requirements
- Time-Sensitive Networking (TSN) adds needed technologies

The Case for Anomaly Detection

- In-car networks are vulnerable to misbehaving communication
- E.g., an unexpected latency spike could delay brake signals
- Anomalies can be caused by:
  - Misconfigurations
  - Defects
  - Cyber-attacks

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➢ Detection of anomalies enables countermeasures

Effects of False Detections

- Anomaly detection is prone to false positives (FPs)
- 99.9991% precision with ~1ms cycles result in 1 FP/8h
- False positives trigger unnecessary countermeasures
- This disruption frequency is unacceptable for drivers

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➢Anomaly detection must maximize precision

Using TSN for Anomaly Detection

Previous work used Per-Stream Filtering and Policing (PSFP)

- Detection of misbehavior without false positives is possible

Asynchronous Traffic Shaping may improve detection

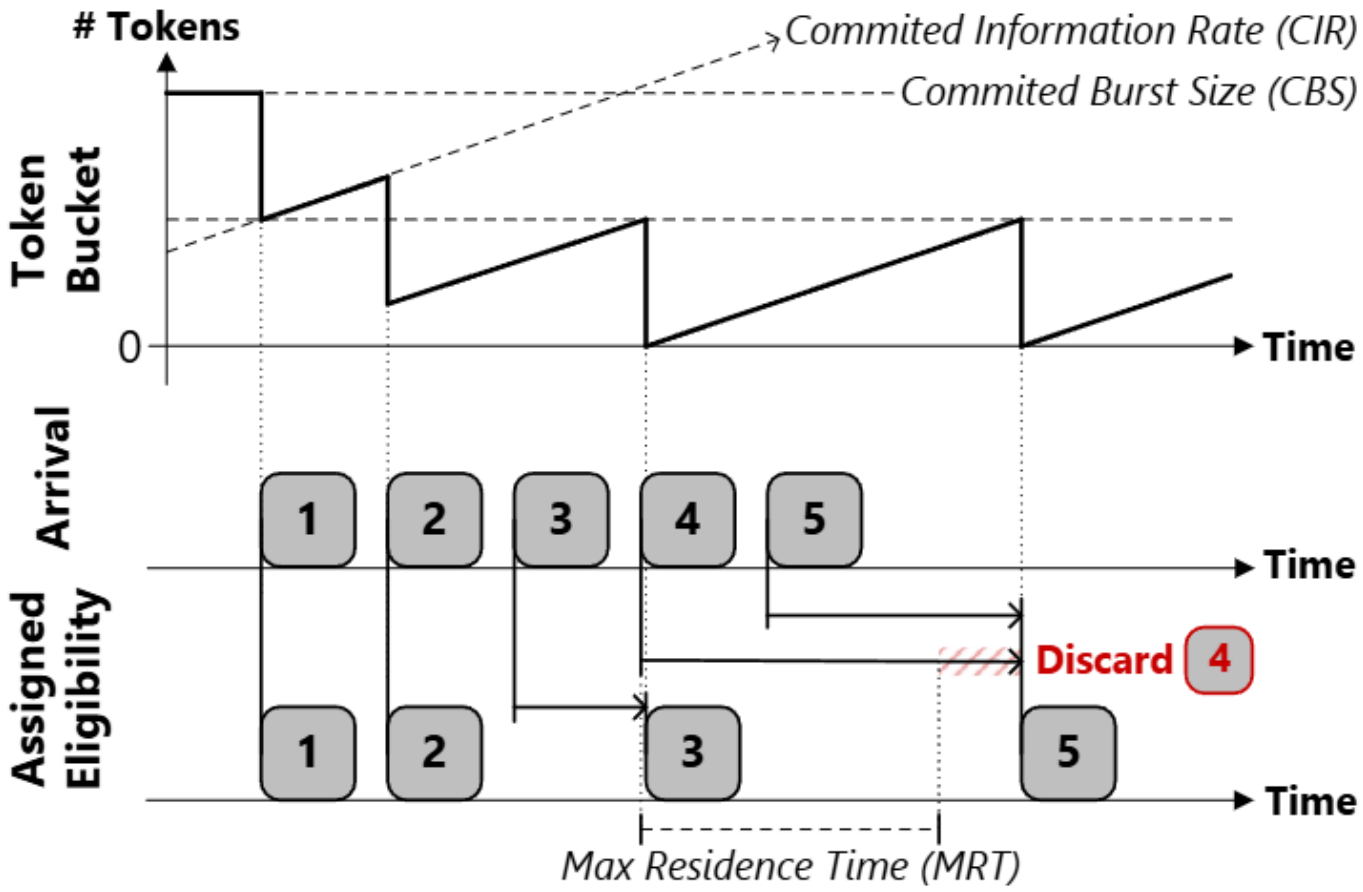
- Configuration is already essential for critical driving functions
- Can be independently used for anomaly detection

II.

Detecting Anomalies with Asynchronous Traffic Shaping

Asynchronous Traffic Shaping (ATS)

- Token-bucket-based per-stream shaping
- Scheduler assigns frames an eligibility time
- Egress queues sort frames by eligibility time
- MRT limits the maximum eligibility time delta



Asynchronous Traffic Shaping (ATS)

ATS schedulers are organized in groups:

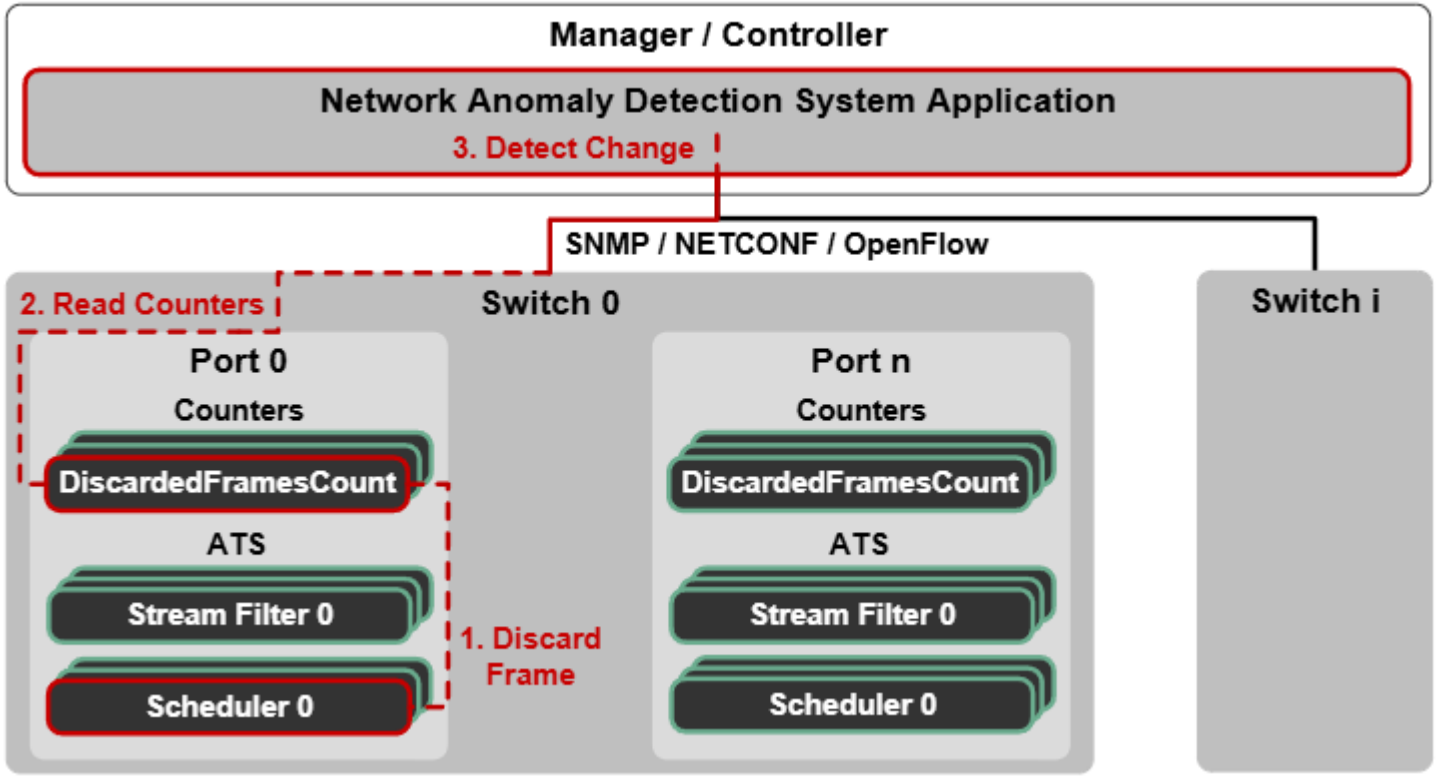
- One group per incoming port and priority
- Keeps order between streams already shaped at previous hop
- Enforced by: eligibility time >= group eligibility time

ATS frame size is limited by the CBS:

- Maximum data unit size must be filtered before scheduling

Network Anomaly Detection System (NADS)

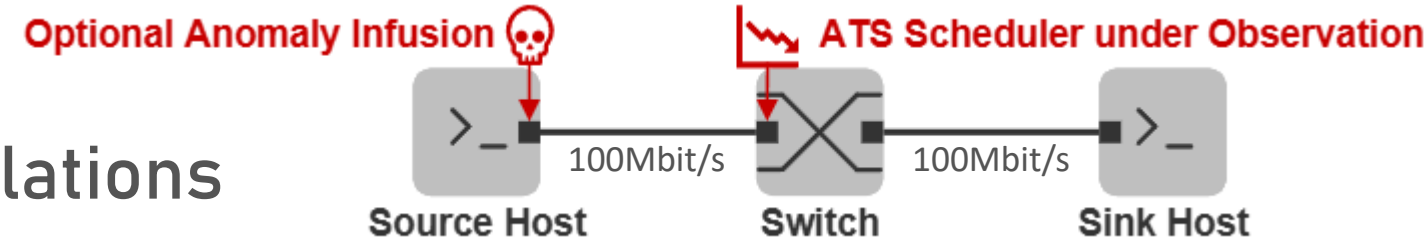
- NADS builds on strict ATS configurations
- Central instance collects ATS statistics
- Application analyzes statistics for deviations



III.

Benchmarking Detection Performance

Benchmarking Environment



- OMNeT++ based simulations
- Each TSN ingress operates independently

➢ Represents an arbitrary hop in any network

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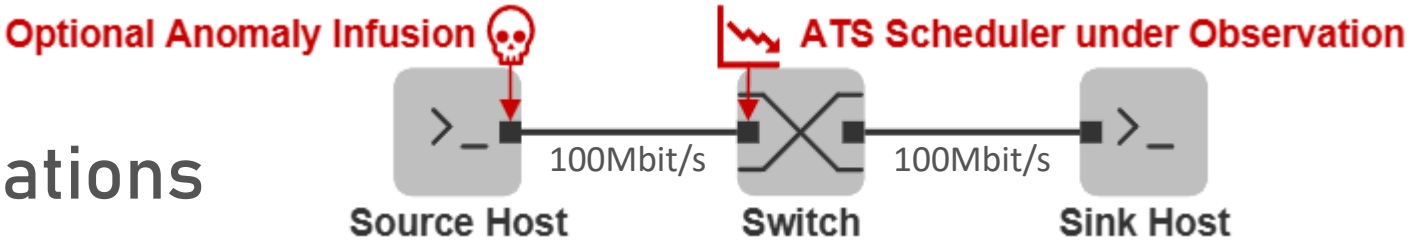

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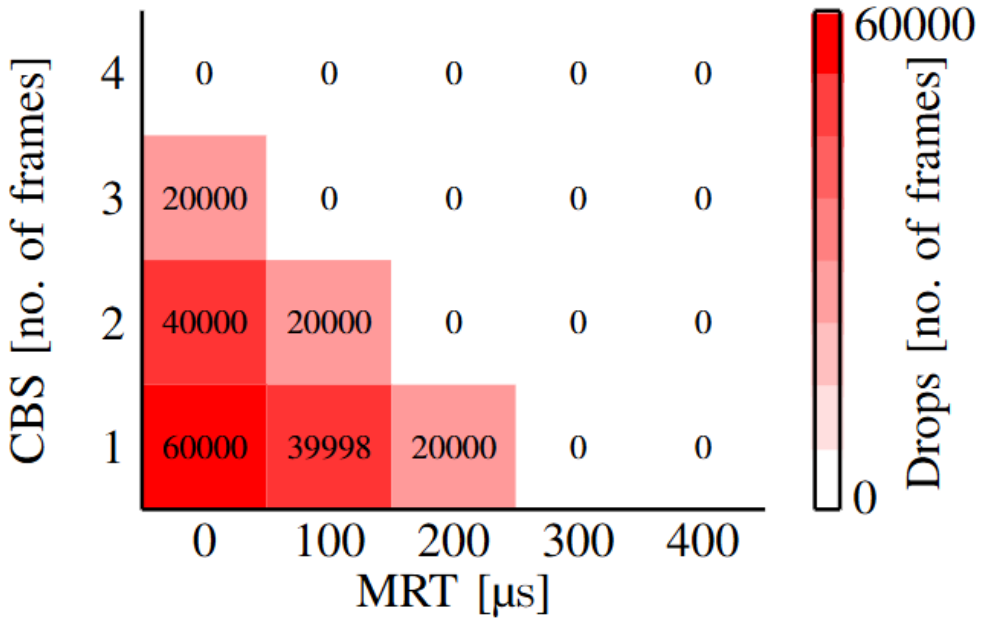
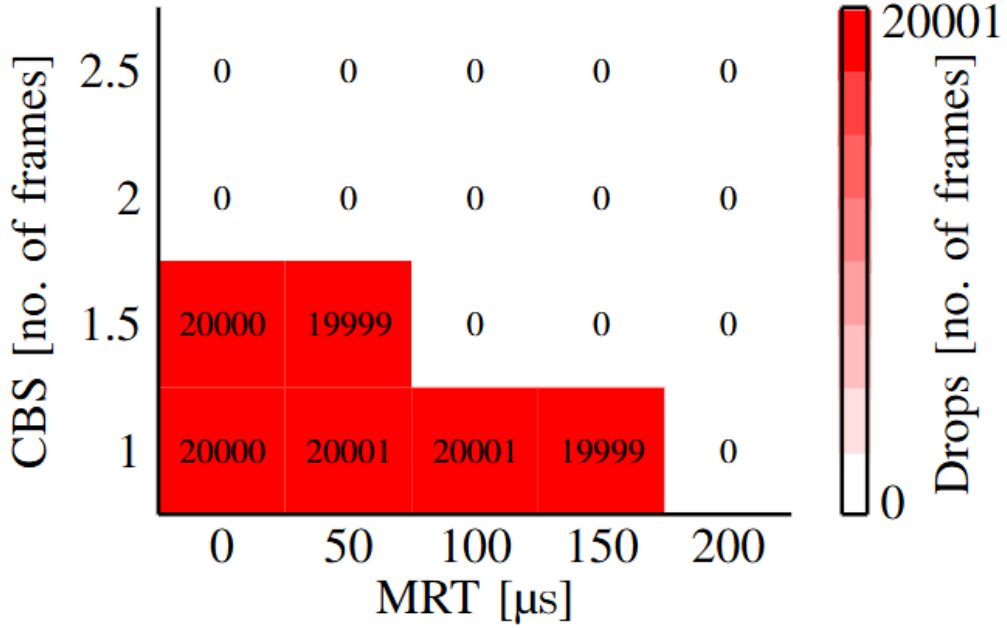
Priority	Traffic	Single ATS stream	Concurrent ATS streams
7	gPTP	Sync interval 0.125s	
6	Synchronous timed traffic	Frame size 1526B, interval 500us	
5	Asynchronous data stream	Frame size 276B, interval 125us	2 x Frame size 276B, interval 250us
4	Cyclic control signal	Frame size 110B, interval 500us	
0	Best effort traffic	Frame size 64B – 1526B, interval 125us – 500us	

ATS Configuration

Single ATS stream



Concurrent ATS streams



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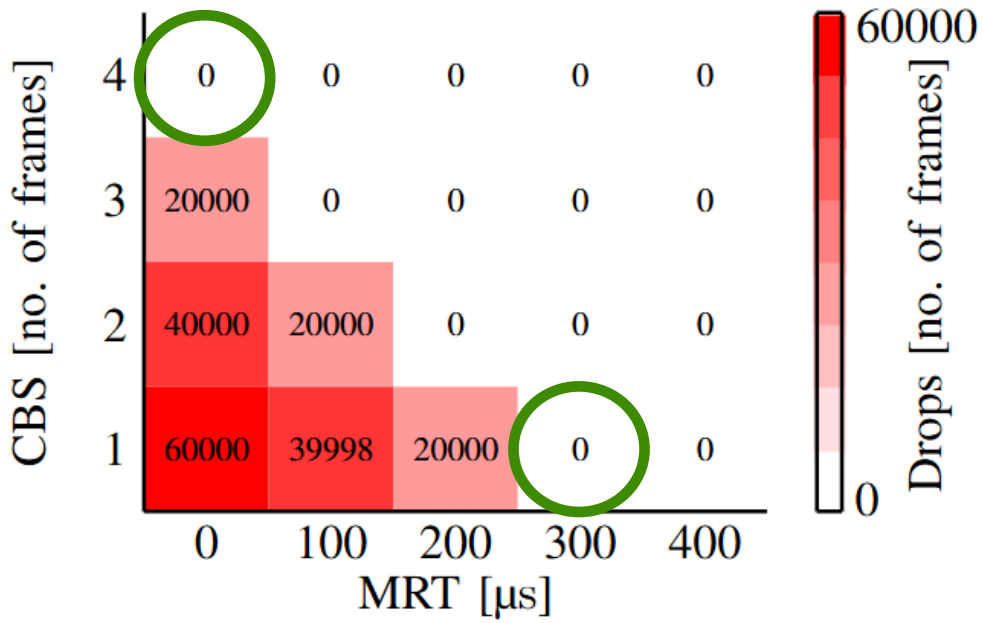

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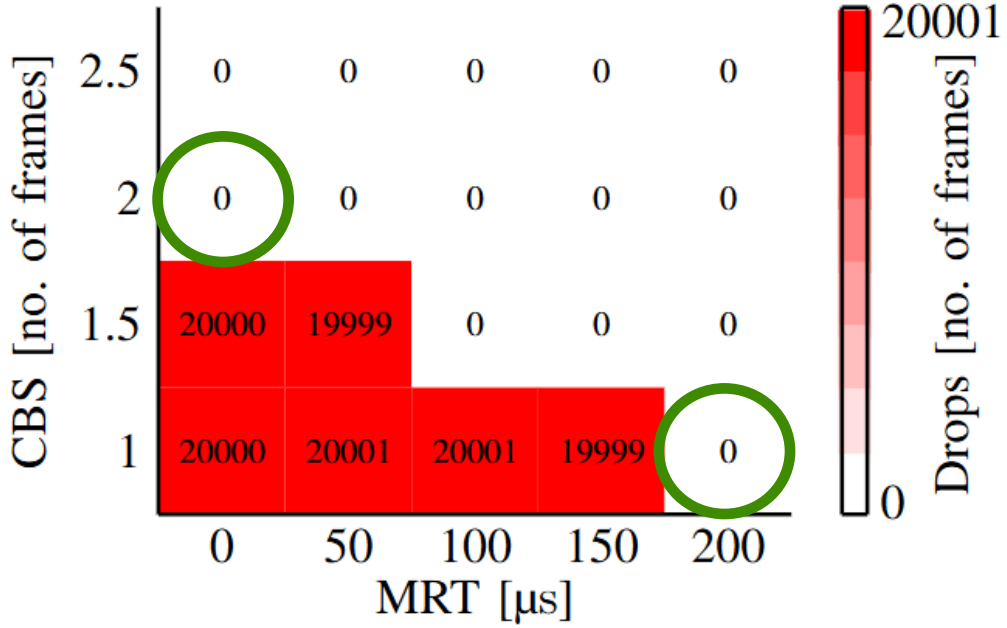


- MRT and CBS can be weighted against each other
- There are zero false positives in any valid scenario

Fundamental Link-Layer Anomalies

Valid

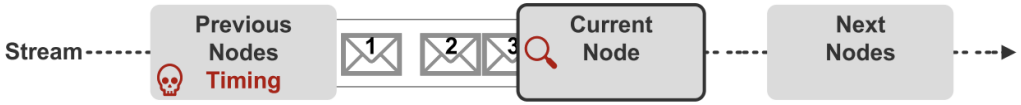
Manipulation

Elimination

Reordering

Injection

Rescheduling



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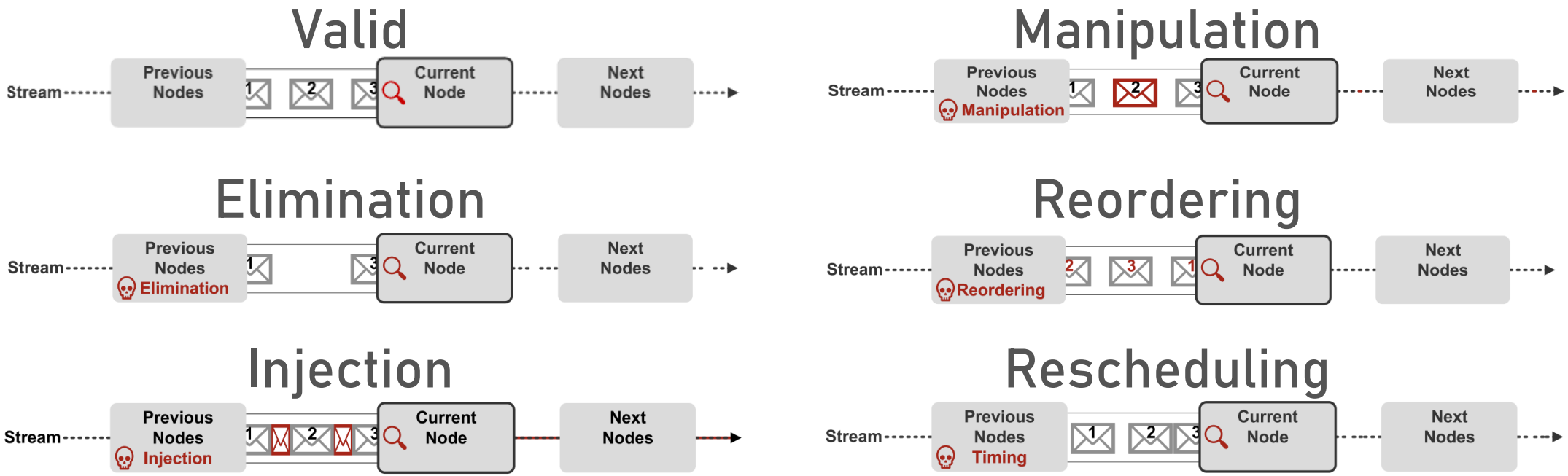

➢ Complex misbehavior falls into at least one of these classes

Single Stream Scenarios Results

Layer	Traffic pattern	Elimination			Injection			Manipulation			Reordering			Rescheduling		
		TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R
Application	Credit-based stream (CBM)	0	8918	0.00	0	9412	0.00	0	8880	0.00	0	8875	0.00	0	8882	0.00
	Credit-based stream (Tokens)	0	8003	0.00	2238	7173	0.24	1814	6183	0.23	30	7973	0.00	12	7985	0.00
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	ATS stream (MRT=0, CBS=4)	26	7937	0.00	8571	842	0.91	7226	774	0.90	3448	4515	0.43	1907	6093	0.24
	ATS stream (MRT=300, CBS=1)	22	7986	0.00	9180	228	0.98	7266	741	0.91	3420	4588	0.43	1977	6030	0.25
Link	Credit-based stream (CBM)	0	8367	0.00	8931	483	0.95	5862	2513	0.70	2	8389	0.00	1	8378	0.00
	Credit-based stream (Tokens)	0	8131	0.00	6255	3156	0.66	2532	5718	0.31	6	8155	0.00	21	8194	0.00
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Link	Credit-based stream (CBM)	0	8367	0.00	8931	483	0.95	5862	2513	0.70	2	8389	0.00	1	8378	0.00
	Credit-based stream (Tokens)	0	8131	0.00	6255	3156	0.66	2532	5718	0.31	6	8155	0.00	21	8194	0.00
	Credit-based stream (Tokens+SDU)	0	8131	0.00	8074	1337	0.86	7034	1216	0.85	6	8155	0.00	21	8194	0.00
	ATS stream (MRT=0, CBS=4)	24	7959	0.00	8368	1045	0.89	7217	773	0.90	2037	5946	0.26	2376	5614	0.30
	ATS stream (MRT=300, CBS=1)	28	7980	0.00	9083	325	0.97	7270	725	0.91	1983	6025	0.25	2356	5639	0.29

Single Stream Scenarios Results

Layer	Traffic pattern	Elimination			Injection			Manipulation			Reordering			Rescheduling		
		TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R
Application	Credit-based stream (CBM)	0	8918	0.00	0	9412	0.00	0	8880	0.00	0	8875	0.00	0	8882	0.00
	Credit-based stream (Tokens)	0	8003	0.00	2238	7173	0.24	1814	6183	0.23	30	7973	0.00	12	7985	0.00
	Credit-based stream (Tokens+SDU)	0	8003	0.00	5717	3694	0.61	4603	3394	0.58	30	7973	0.00	12	7985	0.00
	ATS stream (MRT=0, CBS=4)	26	7937	0.00	8571	842	0.91	7226	774	0.90	3448	4515	0.43	1907	6093	0.24
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	ATS stream (MRT=300, CBS=1)	28	7980	0.00	9083	325	0.97	7270	725	0.91	1983	6025	0.25	2356	5639	0.29

- ATS enables higher detection rates with zero false positives
- Detection of reordering and rescheduling is possible

Concurrent Streams Scenarios Results

Layer	Traffic pattern	Elimination			Injection			Manipulation			Reordering			Rescheduling		
		TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R
Application	Credit-based stream (Tokens)	0	6671	0.00	2203	7208	0.23	1329	5359	0.20	13	6658	0.00	0	6688	0.00
	Credit-based stream (Tokens+SDU)	0	6671	0.00	5672	3739	0.60	3394	3294	0.51	13	6658	0.00	0	6688	0.00
	ATS stream (MRT=0, CBS=2)	0	7990	0.00	9282	131	0.99	6776	1218	0.85	4007	3983	0.50	0	7994	0.00
	ATS stream (MRT=200, CBS=1)	0	7985	0.00	9349	64	0.99	6804	1149	0.86	7984	1	1.00	4060	3893	0.51
Link	Credit-based stream (Tokens)	0	7050	0.00	6255	3156	0.66	2231	4940	0.31	42	7124	0.01	18	7116	0.00
	Credit-based stream (Tokens+SDU)	0	7050	0.00	8074	1337	0.86	6142	1029	0.86	42	7124	0.01	18	7116	0.00
	ATS stream (MRT=0, CBS=2)	0	8010	0.00	9245	168	0.98	6766	1228	0.85	4055	3955	0.51	0	7994	0.00
	ATS stream (MRT=200, CBS=1)	0	7999	0.00	9413	0	1.00	6840	1147	0.86	7999	0	1.00	1465	6522	0.18

Concurrent Streams Scenarios Results

Layer	Traffic pattern	Elimination			Injection			Manipulation			Reordering			Rescheduling		
		TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R	TP	FN	R
Application	Credit-based stream (Tokens)	0	6671	0.00	2203	7208	0.23	1329	5359	0.20	13	6658	0.00	0	6688	0.00
	Credit-based stream (Tokens+SDU)	0	6671	0.00	5672	3739	0.60	3394	3294	0.51	13	6658	0.00	0	6688	0.00
	ATS stream (MRT=0, CBS=2)	0	7990	0.00	9282	131	0.99	6776	1218	0.85	4007	3983	0.50	0	7994	0.00
	ATS stream (MRT=200, CBS=1)	0	7985	0.00	9349	64	0.99	6804	1149	0.86	7984	1	1.00	4060	3893	0.51
Link	Credit-based stream (Tokens)	0	7050	0.00	6255	3156	0.66	2231	4940	0.31	42	7124	0.01	18	7116	0.00
	Credit-based stream (Tokens+SDU)	0	7050	0.00	8074	1337	0.86	6142	1029	0.86	42	7124	0.01	18	7116	0.00
	ATS stream (MRT=0, CBS=2)	0	8010	0.00	9245	168	0.98	6766	1228	0.85	4055	3955	0.51	0	7994	0.00
	ATS stream (MRT=200, CBS=1)	0	7999	0.00	9413	0	1.00	6840	1147	0.86	7999	0	1.00	1465	6522	0.18

- ATS sensitivity to the frame order increases with MRT > 0
- Detection is enhanced with higher frame order sensitivity

IV.

Conclusion & Outlook

Conclusion

- ATS independently describes normal stream behavior
- MRT and CBS jointly influence valid configurations
- ATS improves detection rates with zero false positives
- All anomaly classes except elimination are detectable
- Use for in-vehicular network anomaly detection is feasible

Outlook

- Testing in real-world scenarios
- Exposing to real attack traces
- Comparing against dedicated detection algorithms

Anomaly Detection in Real-Time Networks Using Asynchronous Traffic Shaping

Thank you for your attention!

All simulations are available as open source

https://github.com/CoRE-RG/NIDSDatasetCreation

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