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Timing-based anomaly detection in SCADA networks

Chih-Yuan Lin, Simin Nadjm-Tehrani
and Mikael Asplund
Linköping University, Sweden

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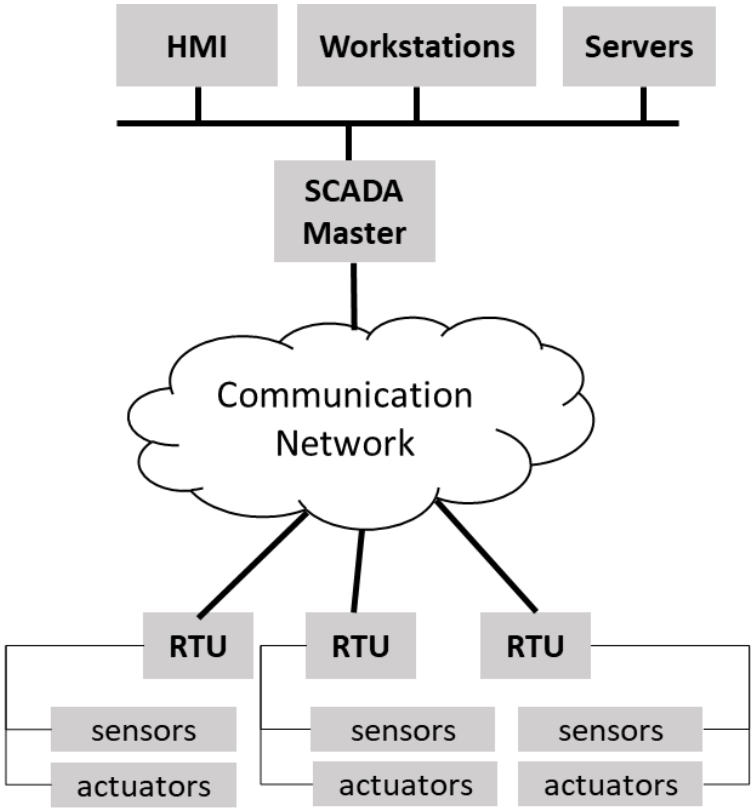
What is SCADA?

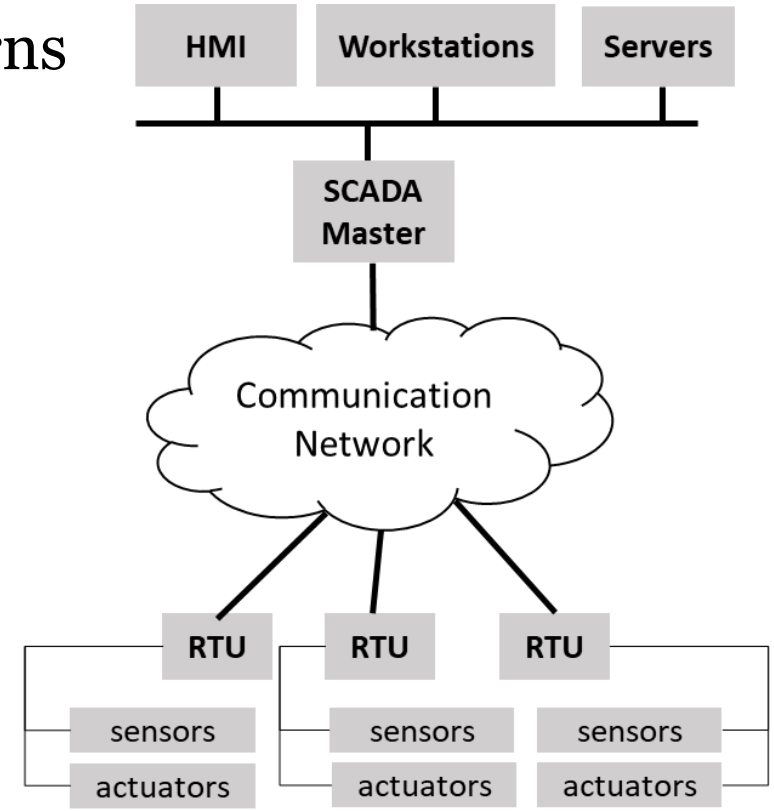
- Supervisory Control And Data Acquisition
- An Industrial automation control system running our modern industries, including *critical infrastructures*
  - Power stations
  - Transportation systems

A simple SCADA architecture



Characteristics of SCADA traffic

- Stable communication patterns



Characteristics of SCADA traffic

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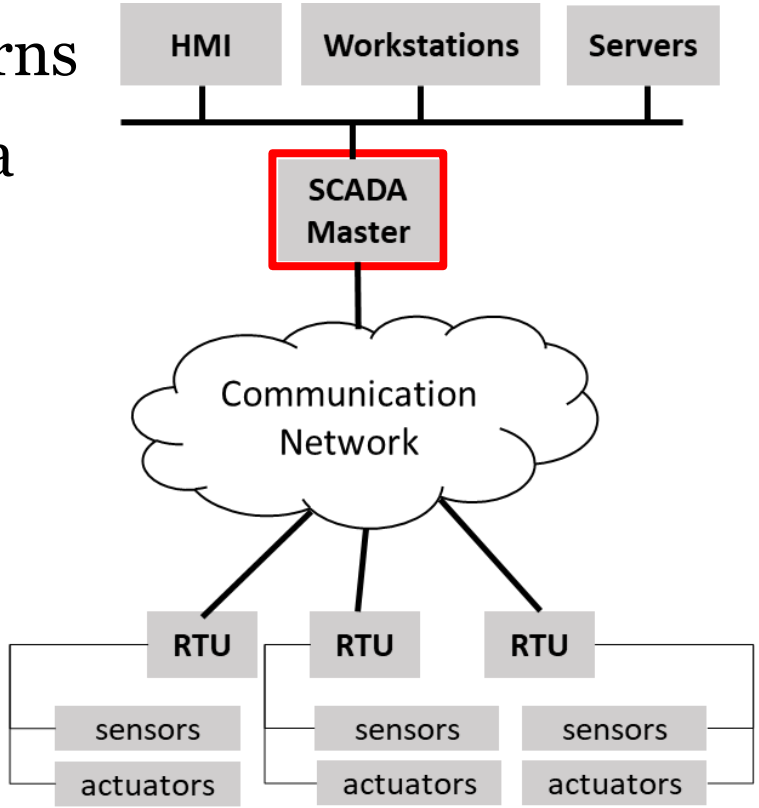
- SCADA master retrieves data from field devices by polling



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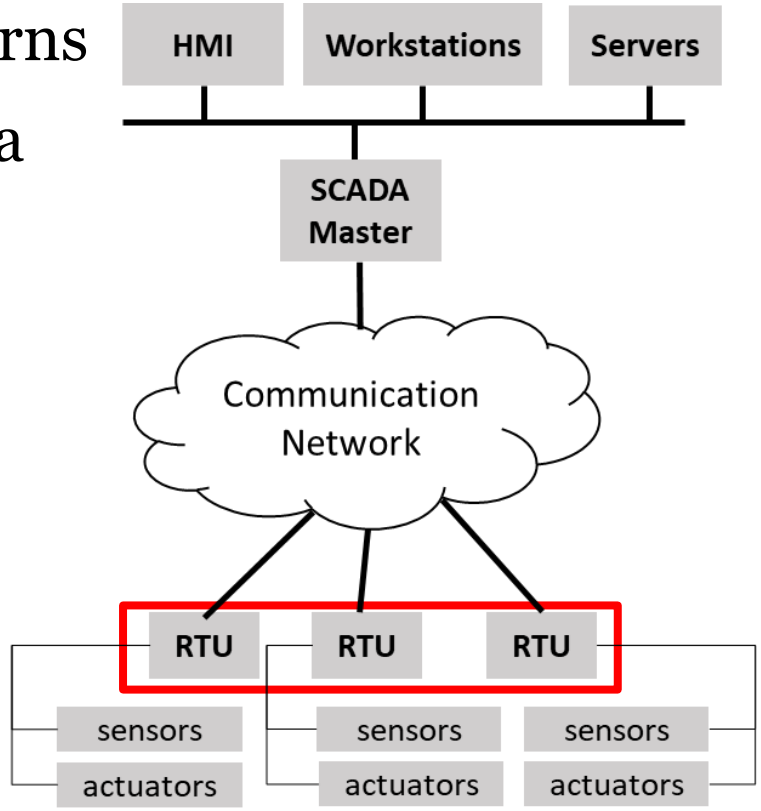
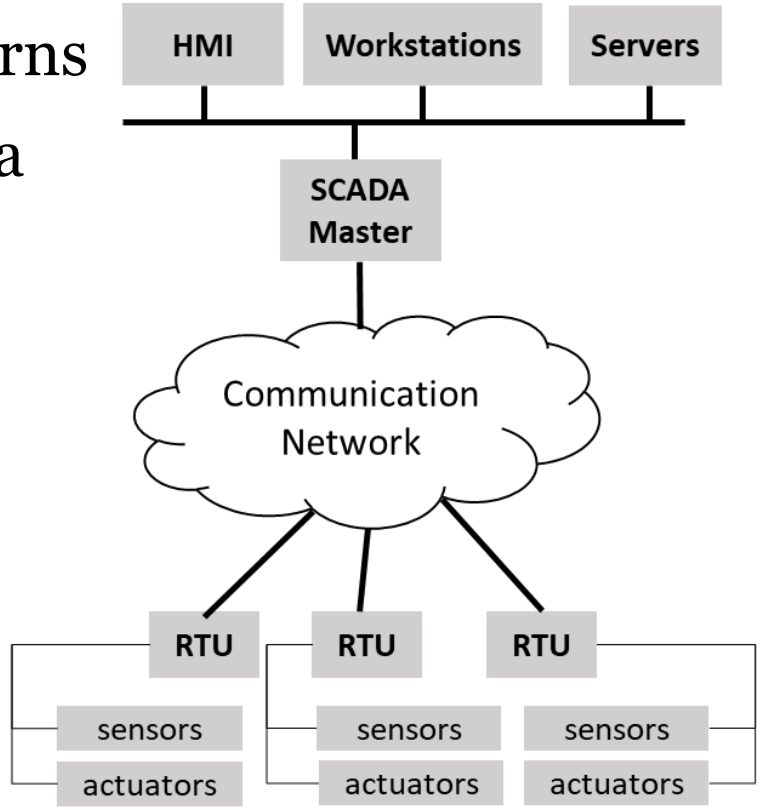


Characteristics of SCADA traffic

- Stable communication patterns
- SCADA master retrieves data from field devices by polling
- Some protocols allow asynchronous messages
- SCADA-specific protocols
  - Siemens S7, Modbus and IEC-104



Threat Model

- Targeted attacks may contain only valid commands/messages
  - Flooding attack
  - Injection attack
  - TCP-sequence prediction attack

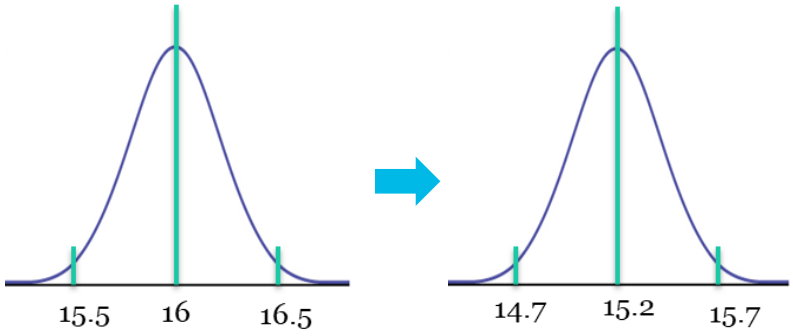
- All these attacks may cause timing anomalies

Our approach

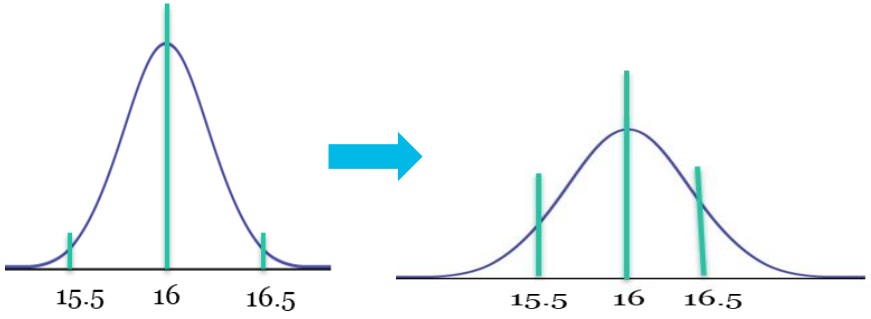
- Timing-based anomaly detection
  - Inter-arrival times of repeated messages
- Sampling distribution of
  - Sample mean
    - average of observations in a sample set
  - Sample range
    - difference of maximum and minimum observation in a sample set

Sample mean & sample range

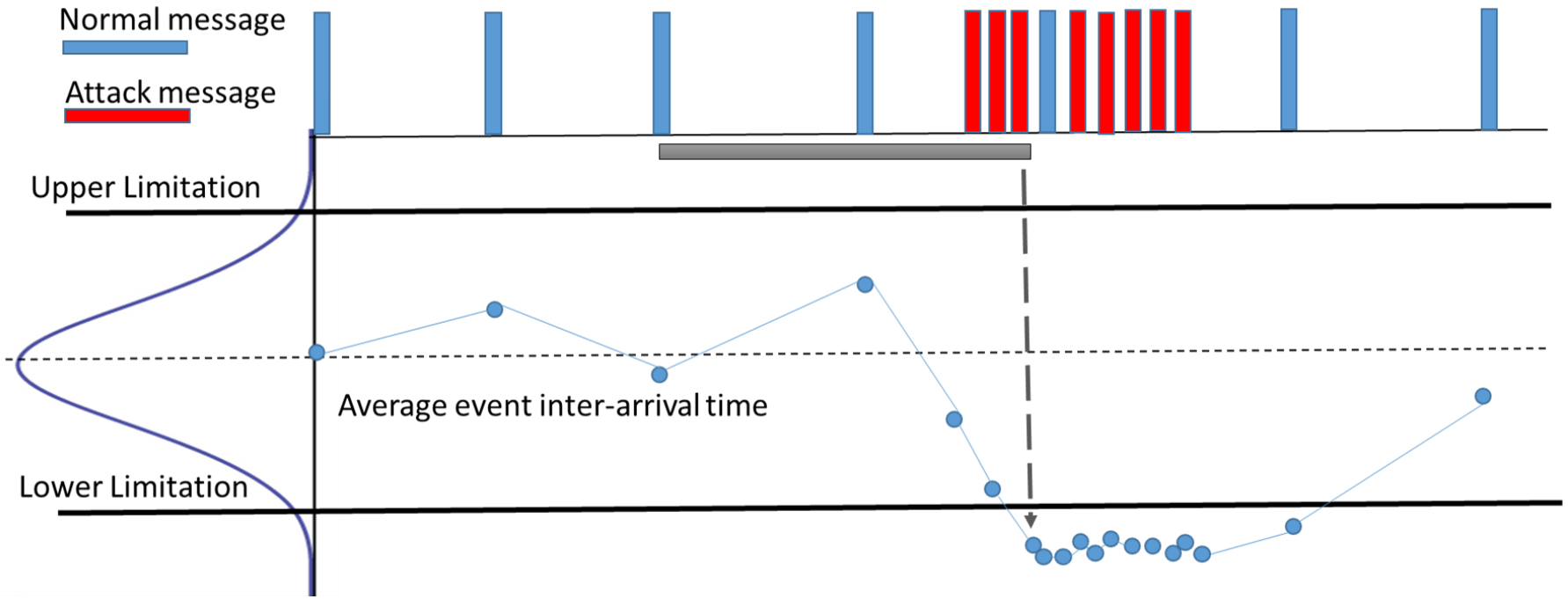
- *Sample mean*
- Can detect shift of central tendency



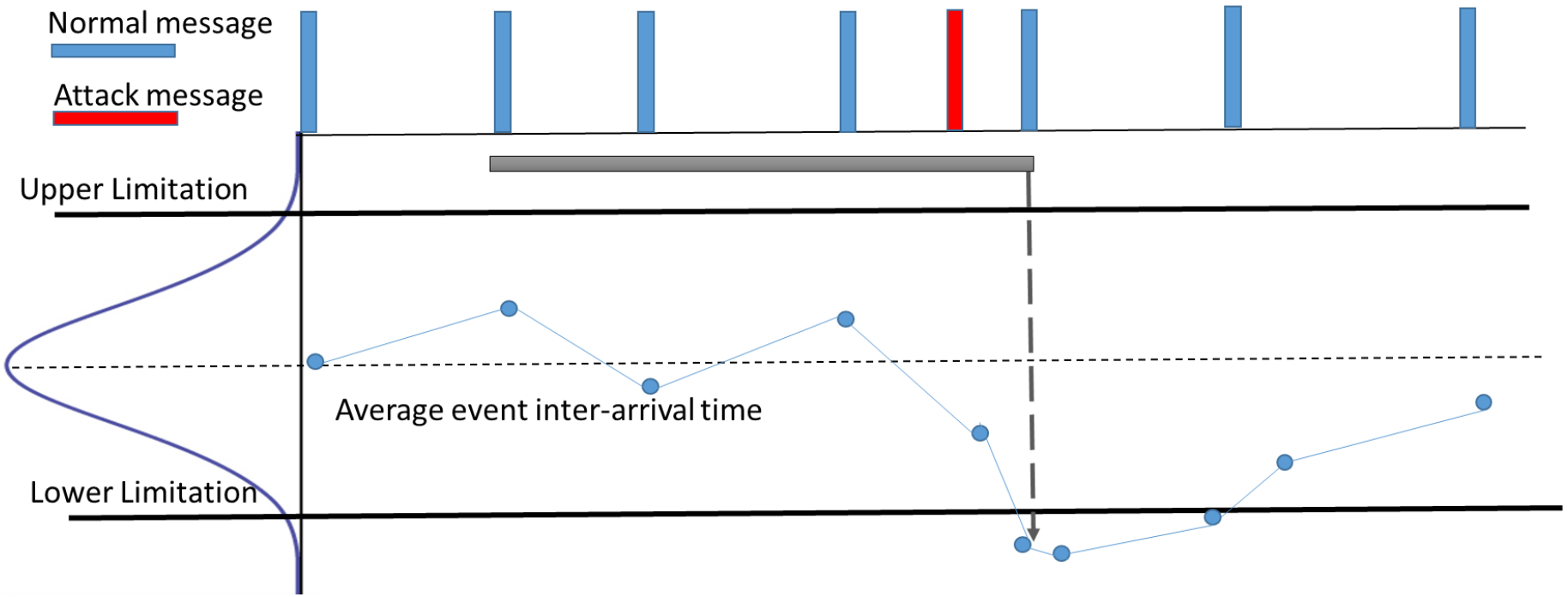
- *Sample range*
- Can detect change of dispersion



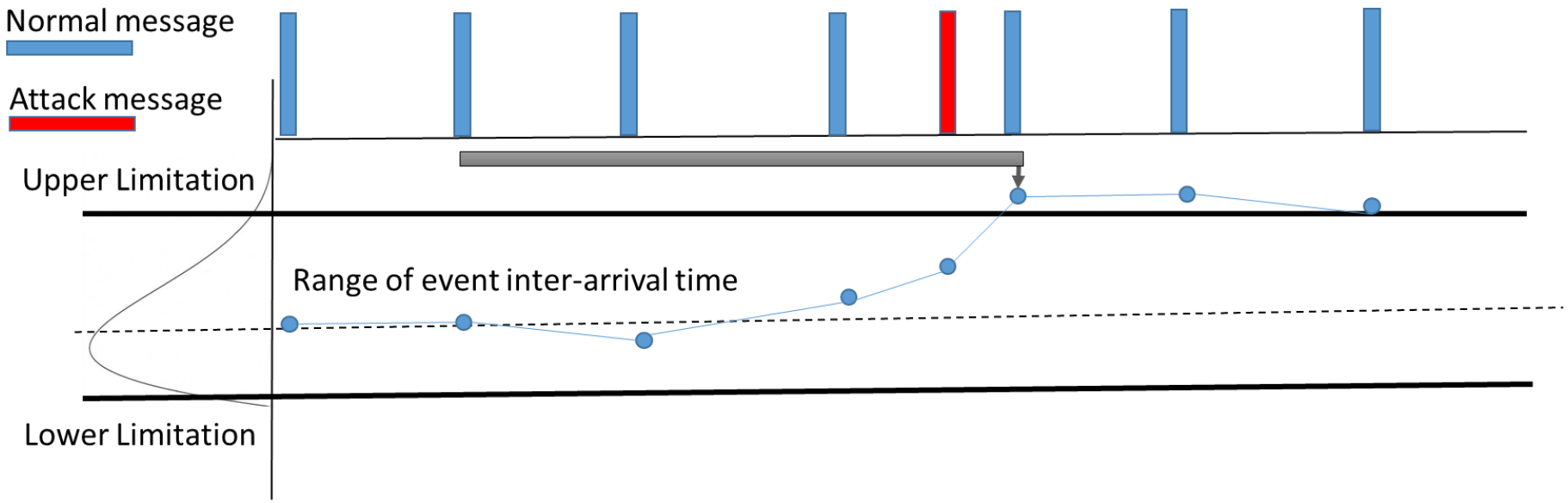
Flooding attack & mean model



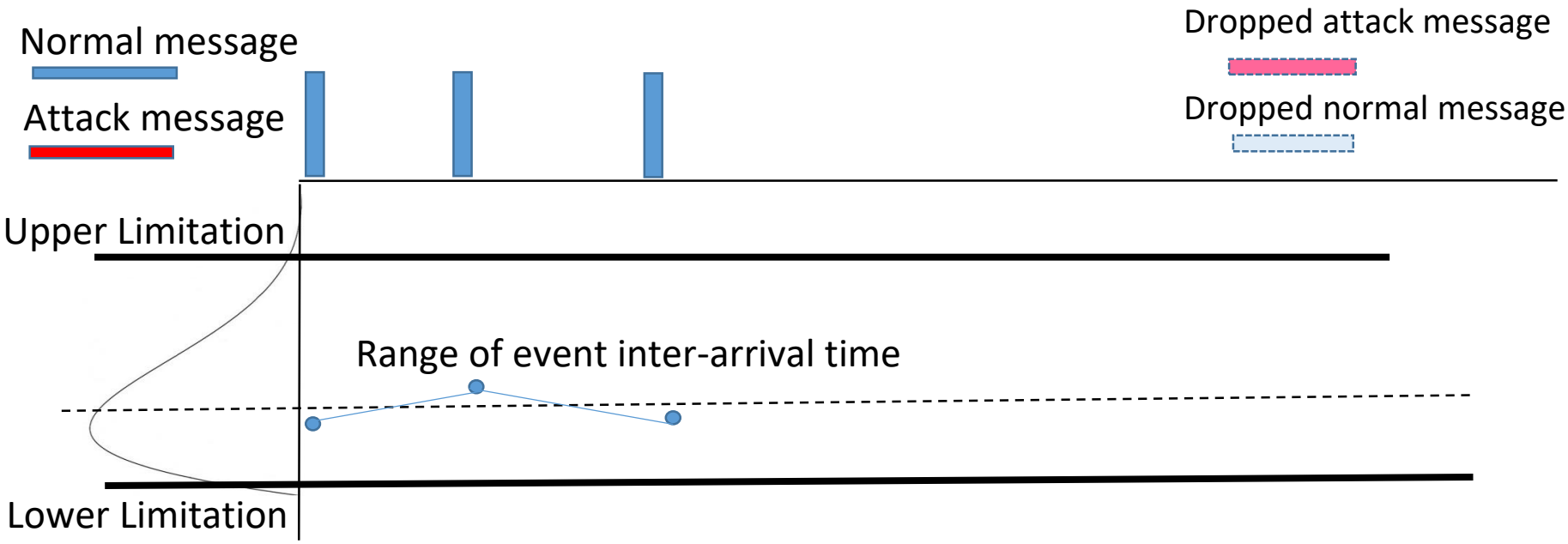
Injection attack & mean model



Injection attack & range model



Prediction attack & range model



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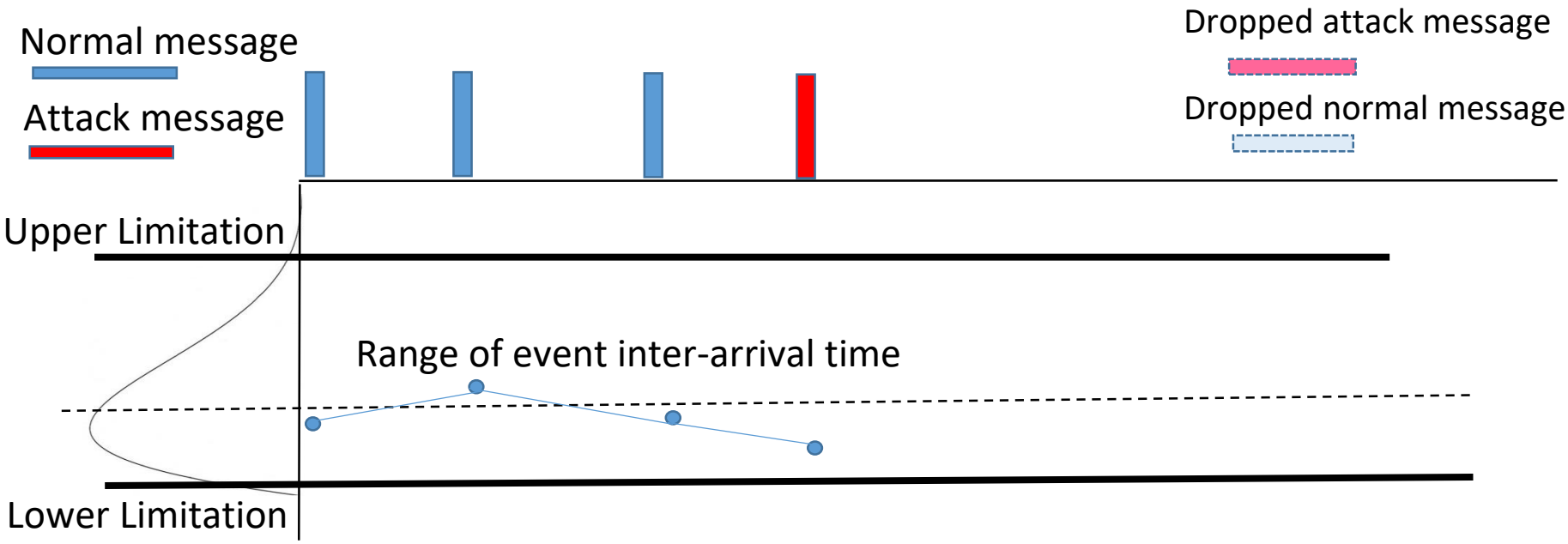

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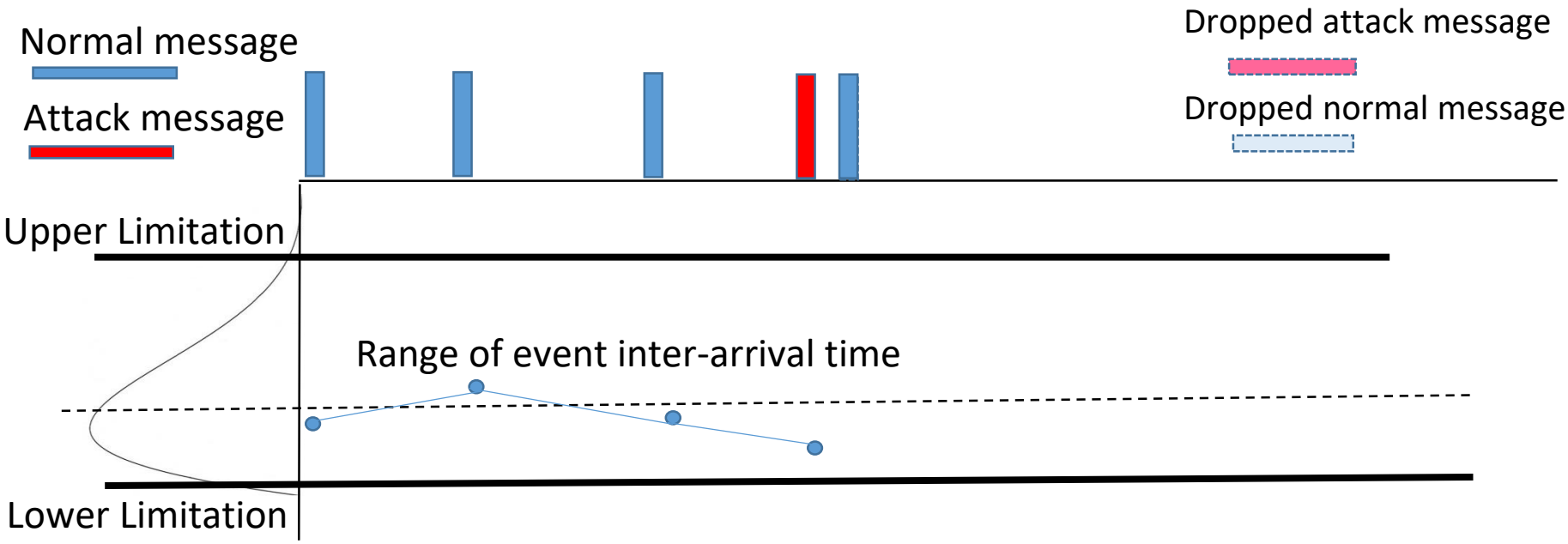

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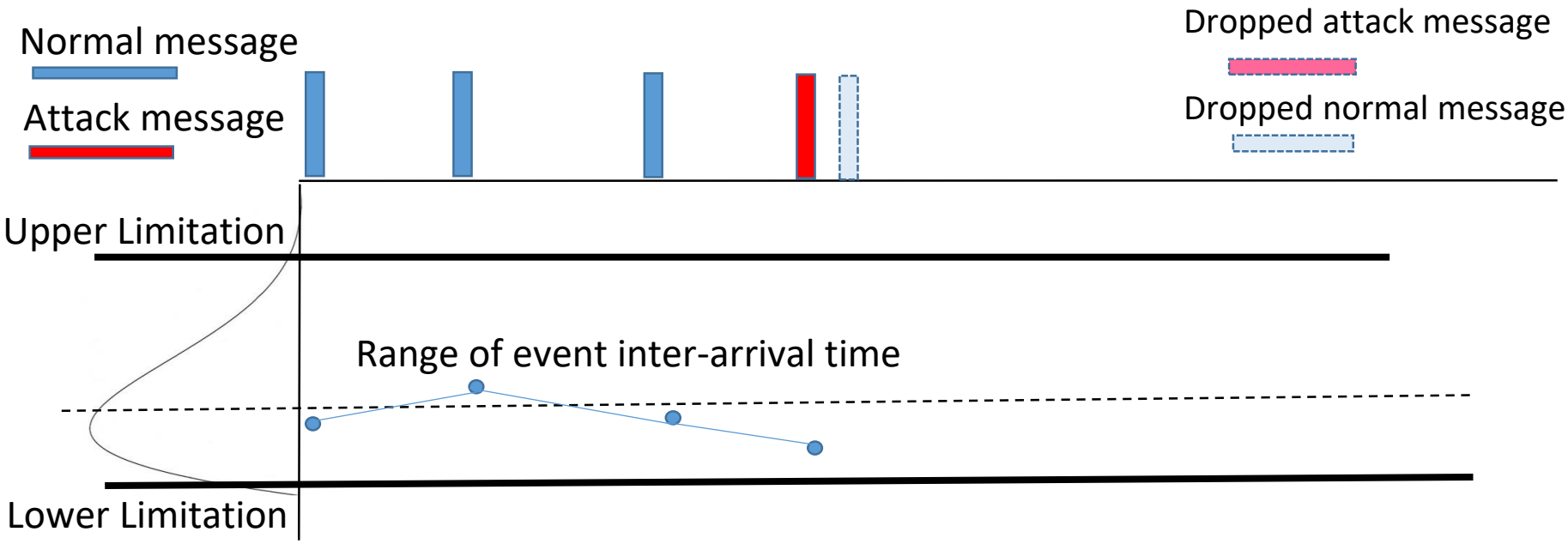

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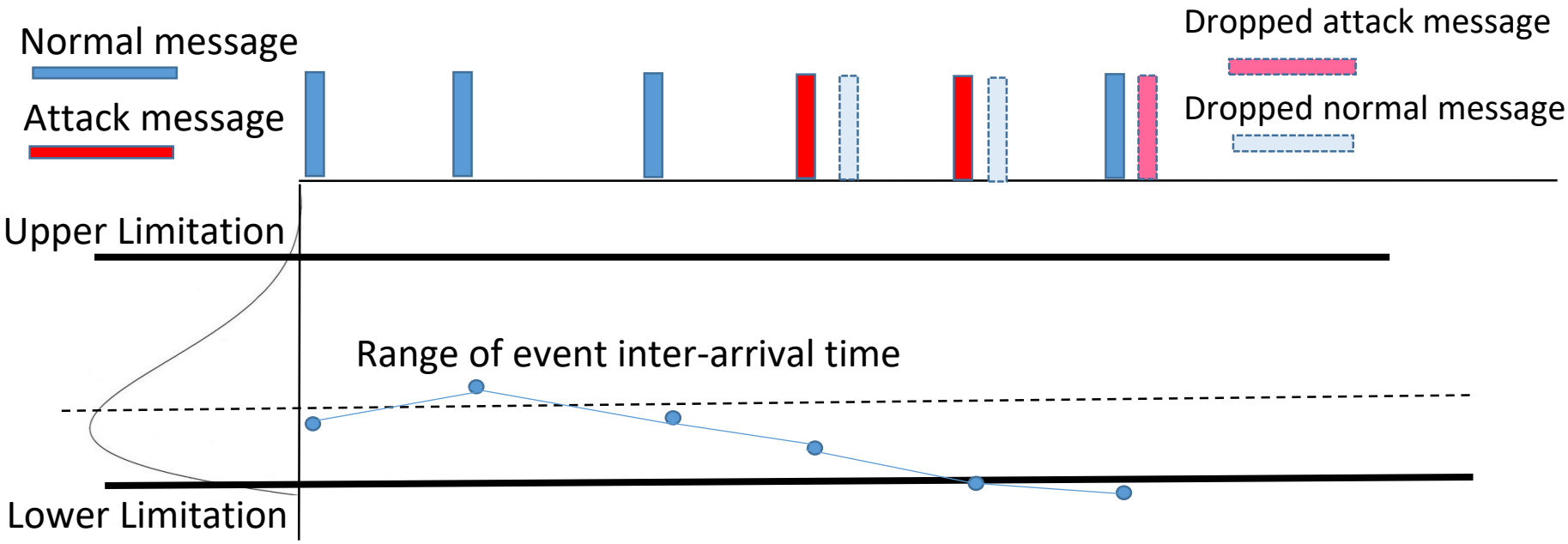
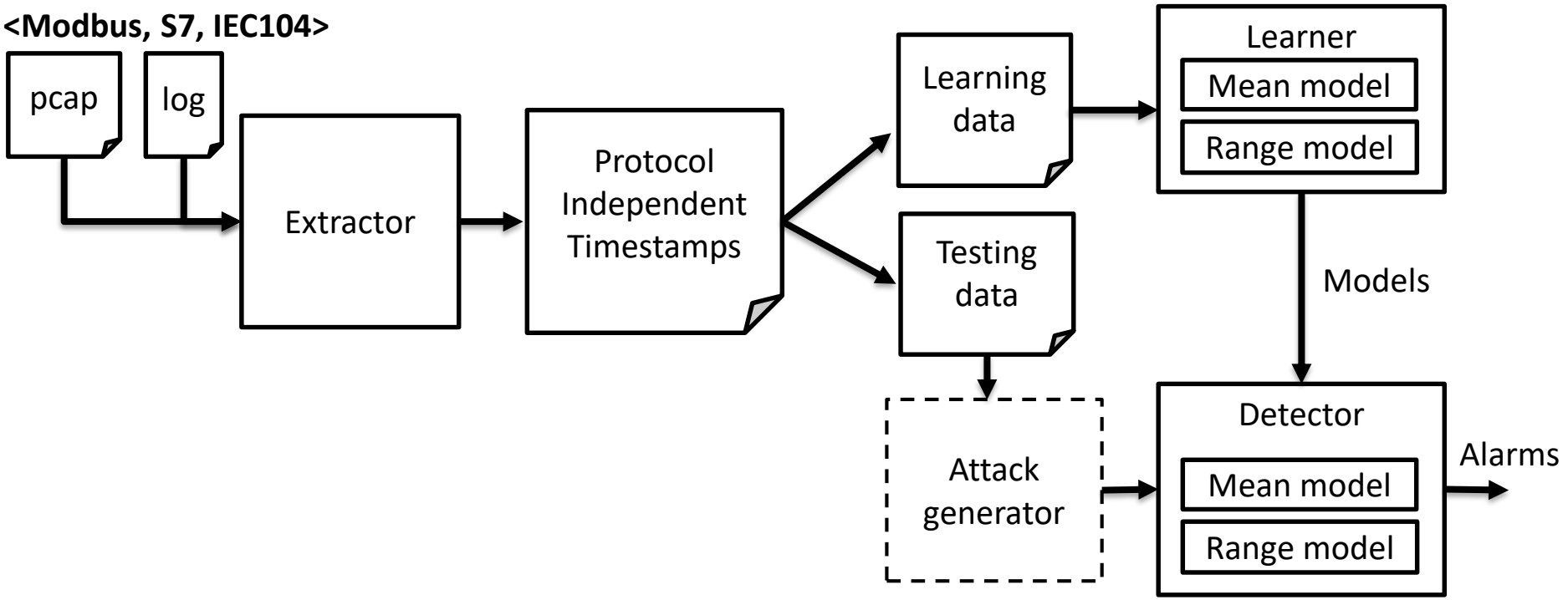


Anomaly detection workflow



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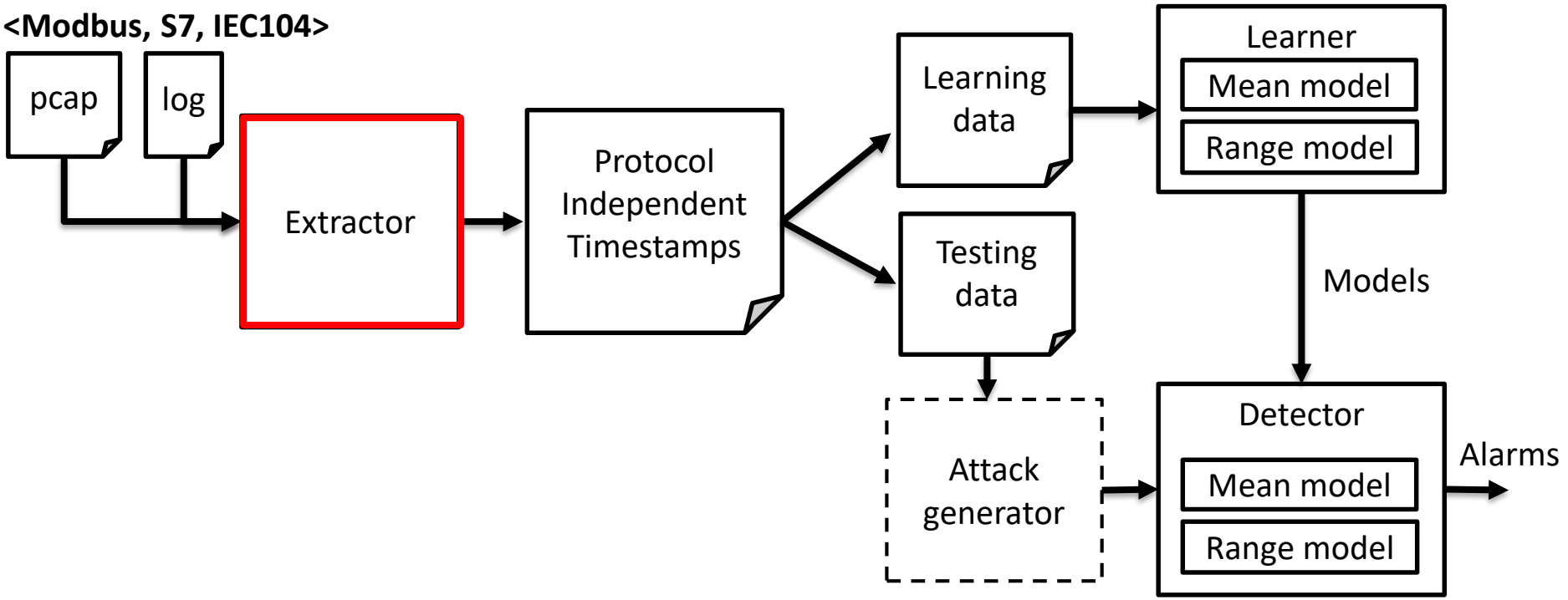

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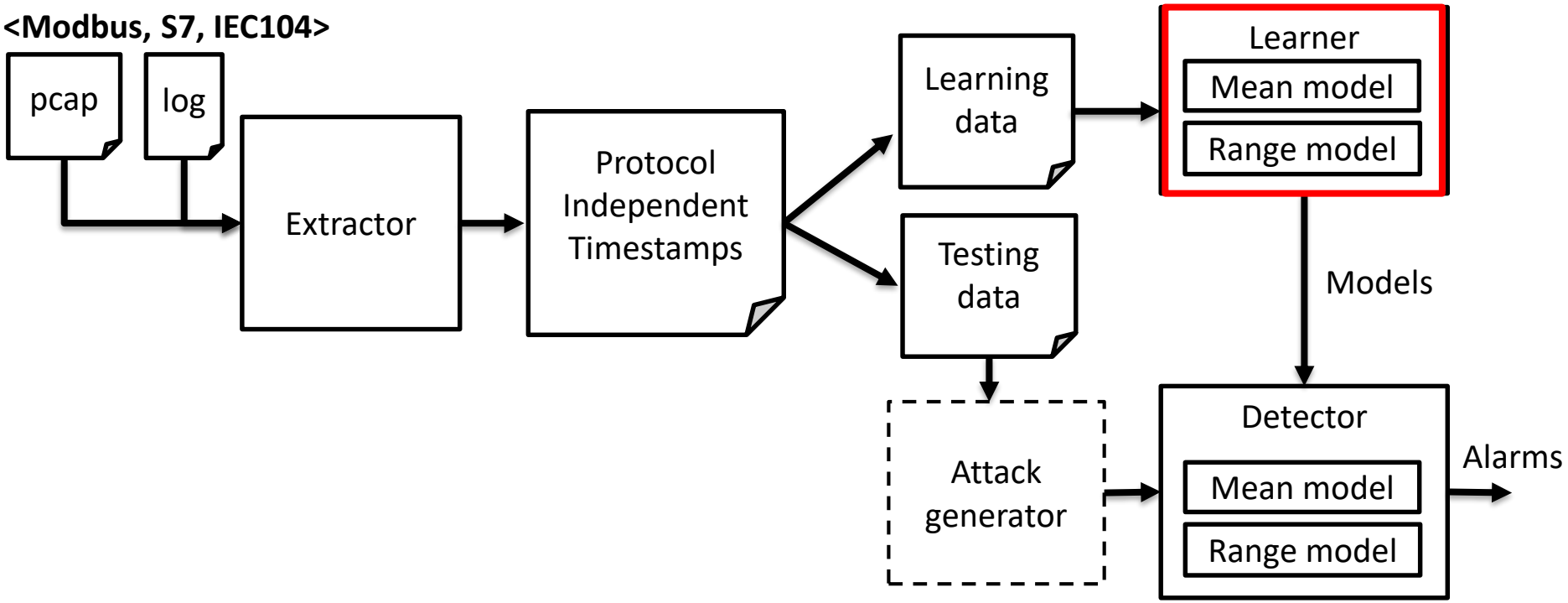

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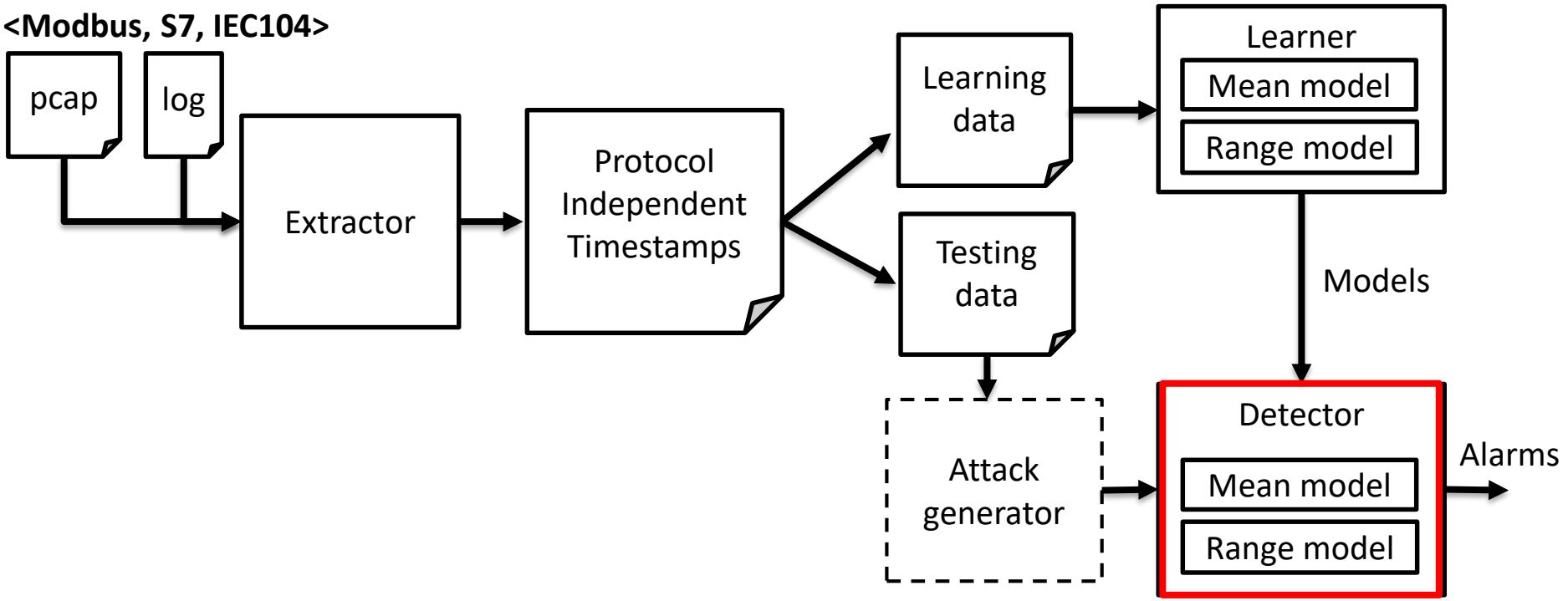
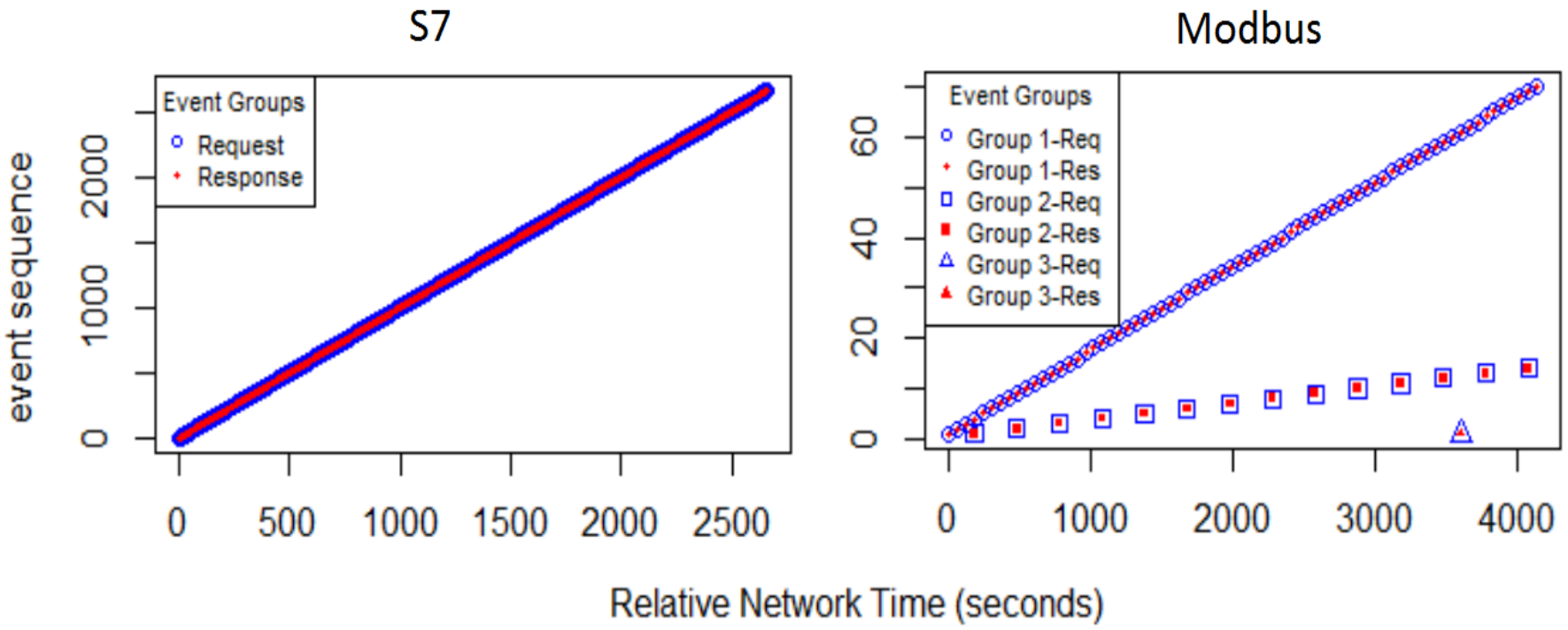


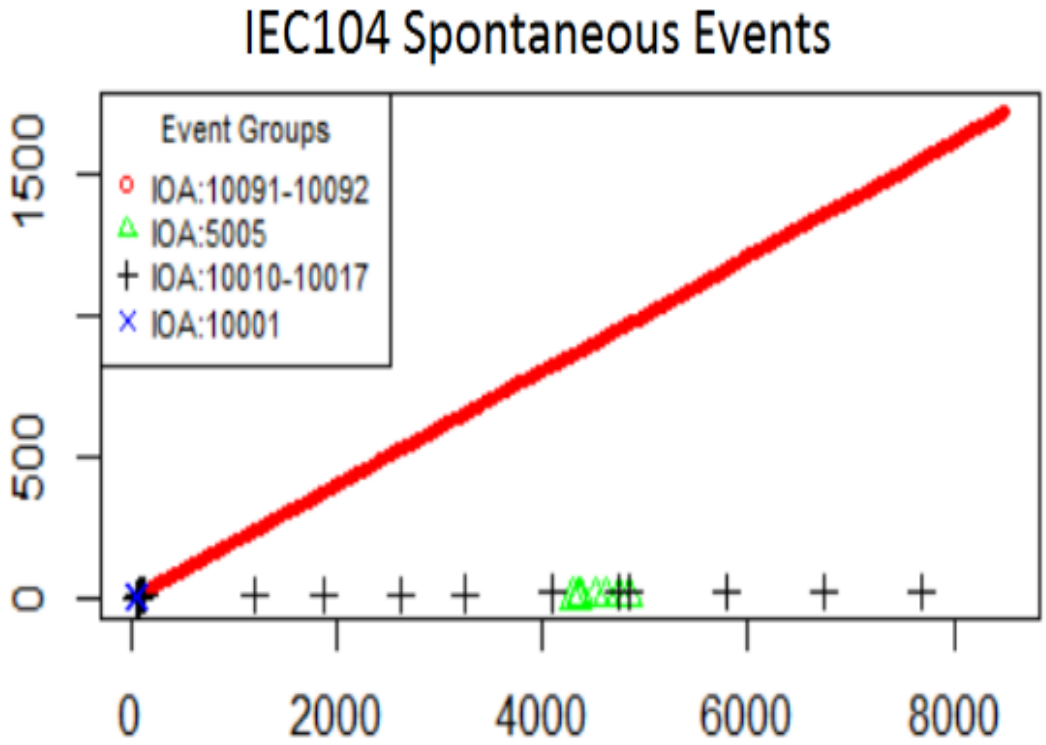
Datasets

- Modbus RTU- from actual building ventilation system
  - Synchronous request-response communication mode
- Siemens S7-simulated in 4SICSLab
  - with real Siemens devices
  - Synchronous & asynchronous messages
- IEC 60870-5-104 (IEC-104)- from our emulated testbed
  - Synchronous & asynchronous messages

Periodicity of request-response events



IEC-104 events



Overview of Selected Events

Name	Duration	Avg. period (sec)	Sd. of period (sec)	Number of events
Modbus1-req/res	5 days	59.9	2.8	5984
Modbus2-req/res	5 days	297.9	25.1	1197
S7-req/res	14 hrs	1.0	0.014	53189
IEC104-spont	24 hrs	4.9	2.9	16831

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Evaluation

- $\text{FPR} = \dfrac{\text{number of false alarms}}{\text{number of windows without attacks}}$ (%)
- $\text{TPR} = \dfrac{\text{number of true alarms}}{\text{number of windows with attacks}}$ (%)
- $\text{ODR} = \dfrac{\text{number of detected attack events}}{\text{number of attack events}}$ (%)

Detection Accuracy

	Flooding					Injection					Prediction				
	Mean		Range			Mean		Range			Mean		Range		
	TPR	FPR	TPR	FPR	ODR	TPR	FPR	TPR	FPR	ODR	TPR	FPR	TPR	FPR	ODR
S7-req	99.96	0.01	59.15	0.84	100	96.25	0.01	100	0.89	100	0.12	0	90.6	0.89	99.81
S7-res	99.95	0.21	56.41	1.13	100	96.66	0.2	99.58	1.16	100	0.23	0.2	91.09	1.15	99.51
Modbus1-req	99.84	0	99.69	1.13	100	83.33	0	83.33	1.16	100	0	0	92.86	1.36	99.19
Modbus1-res	99.83	0	99.68	1.15	100	83.33	0	83.33	1.2	100	0	0	91.93	1.4	99.19
Modbus2-req	99.83	0	100	0	100	83.12	0	100	0	100	4.95	0	100	0	100
Modbus2-res	99.83	0	100	0.38	100	83.12	0	100	0.38	100	4.95	0	100	0.32	100
104-spont	98.88	0.42	98.14	1.14	100	2.47	0.42	3.7	1.16	13.33	2.8	0.4	72.44	1.11	92.89

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Conclusions

- Timing-based anomaly detection shown to be promising
- Identified the need for more complicated timing models for modern protocols such as IEC-104

Questions?

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chih-yuan.lin@liu.se

www.rics.se

LINKÖPING UNIVERSITY

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