# CableMon: Improving the Reliability of Cable Broadband Networks via Proactive Network Maintenance

Jiyao Hu*, *Zhenyu Zhou**, Xiaowei Yang,
Jacob Malone, and Jonathan W Williams




*Jiyao Hu and Zhenyu Zhou, placed in the alphabetic order, are the lead student authors and contributed equally to this work.

# Broadband Networks are Important


E-Commerce

Remote Learning

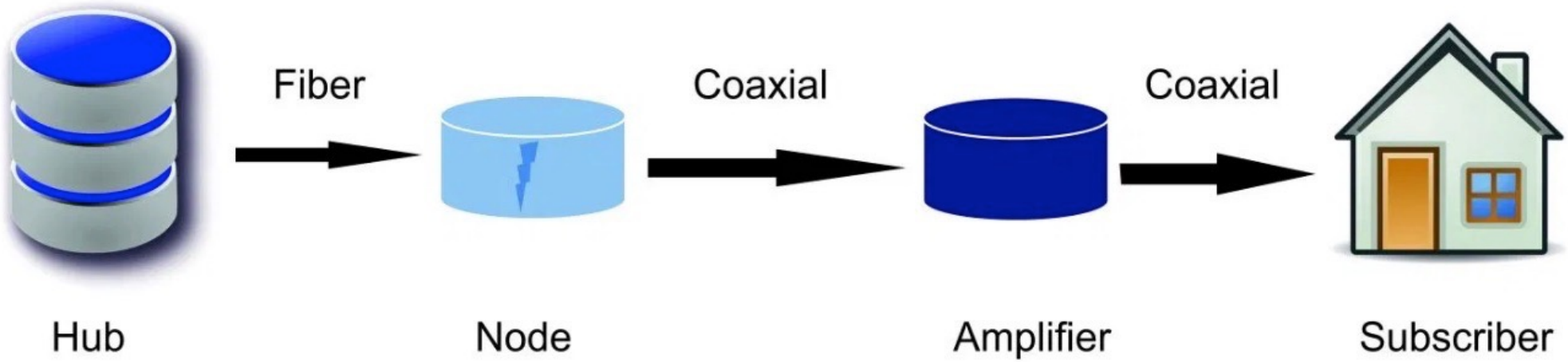
Work from Home

Entertainment

# Cable Broadband: One of Few Choices in U.S.

- Availability to U.S. homes
  - VDSL: 43%
  - FTTP: 29%
  - Cable: 93%

# Cable Networks are Unreliable



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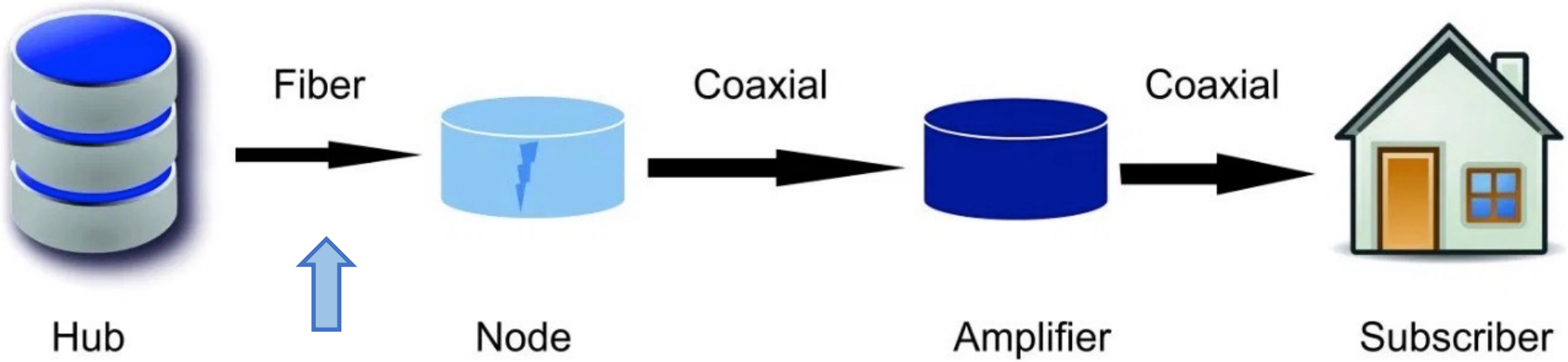

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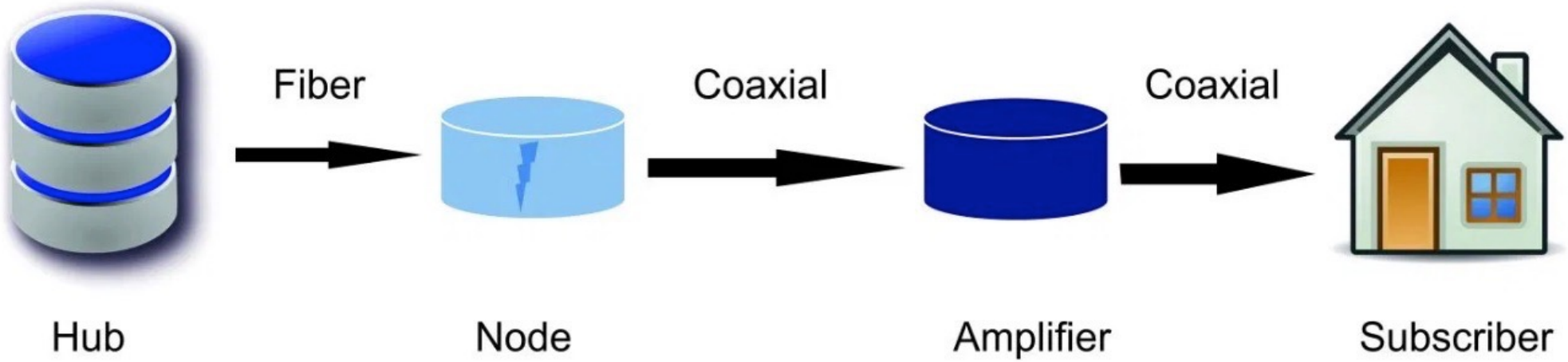

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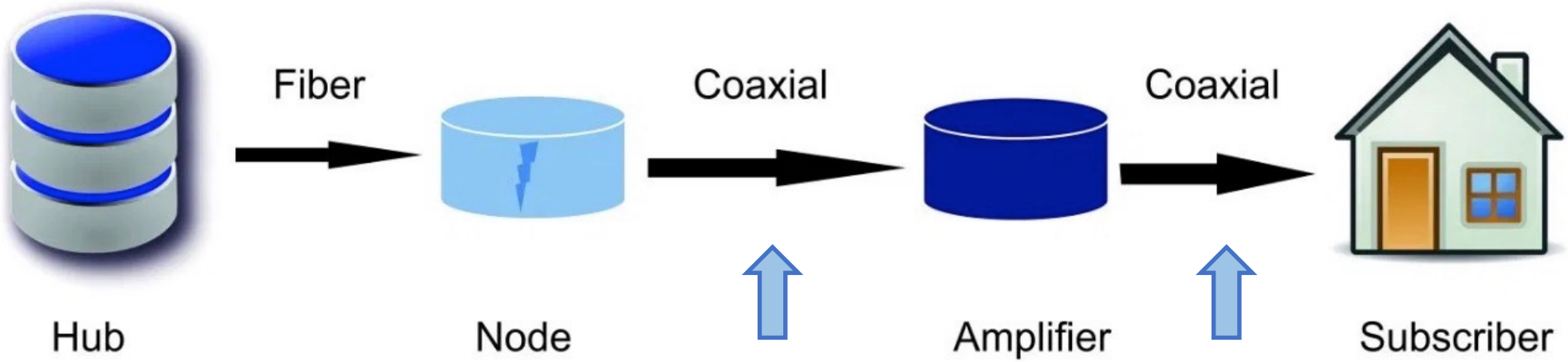

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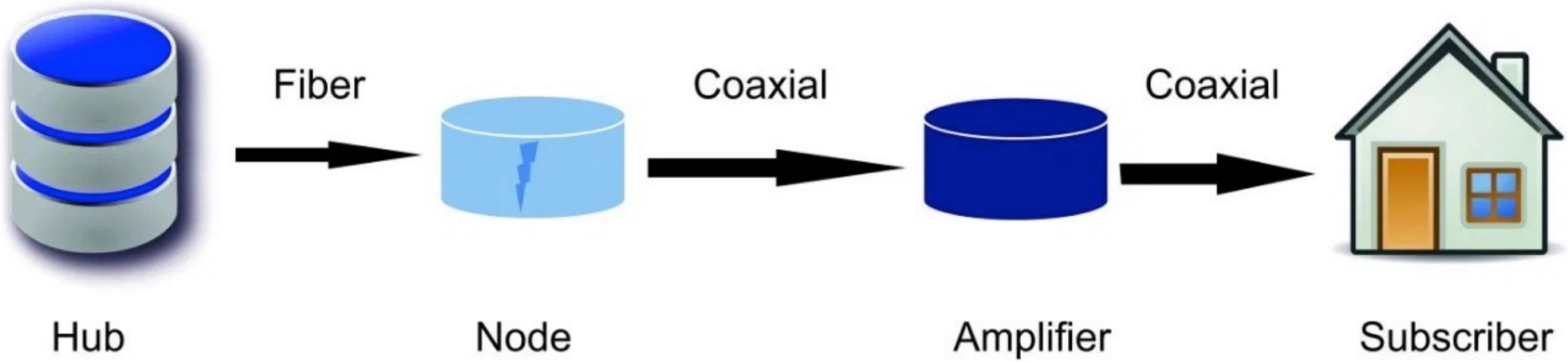

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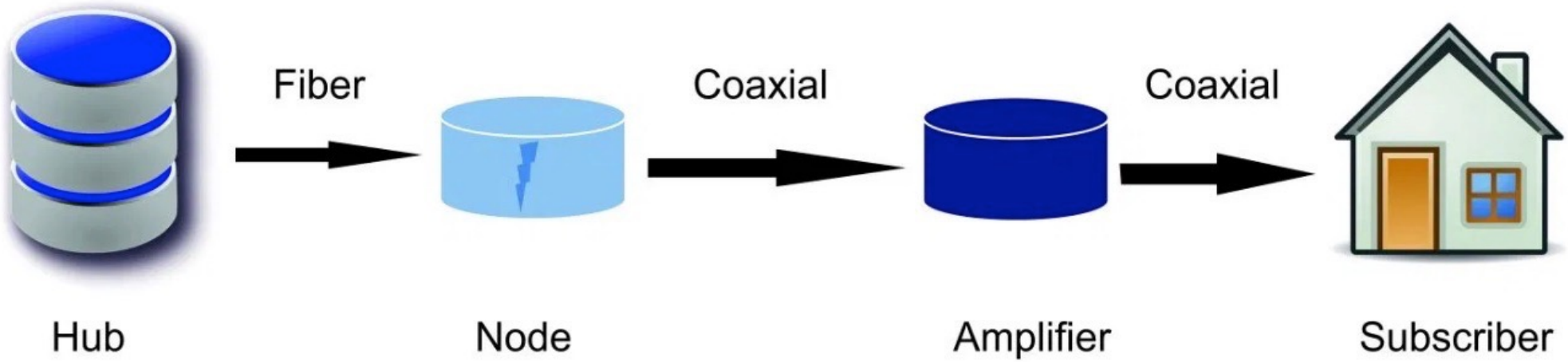


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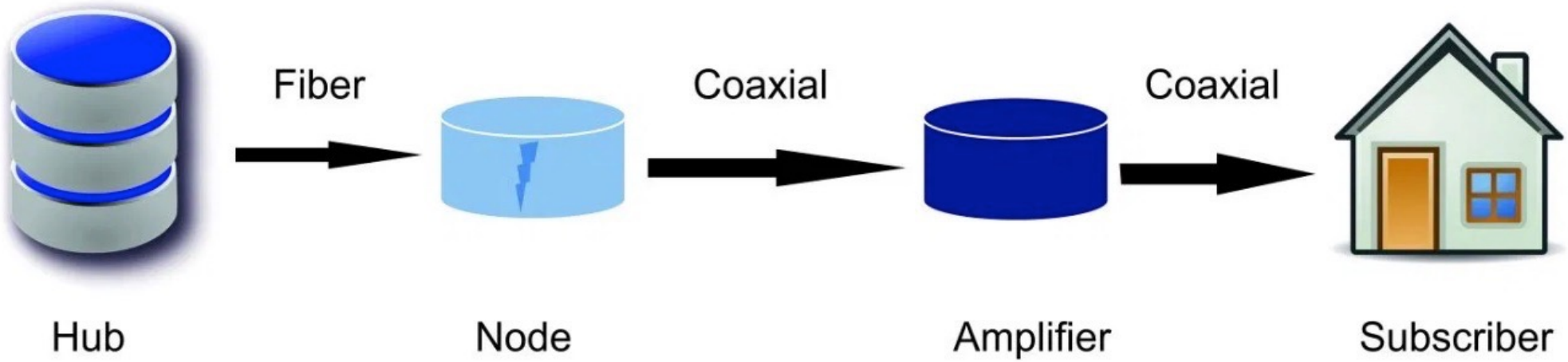


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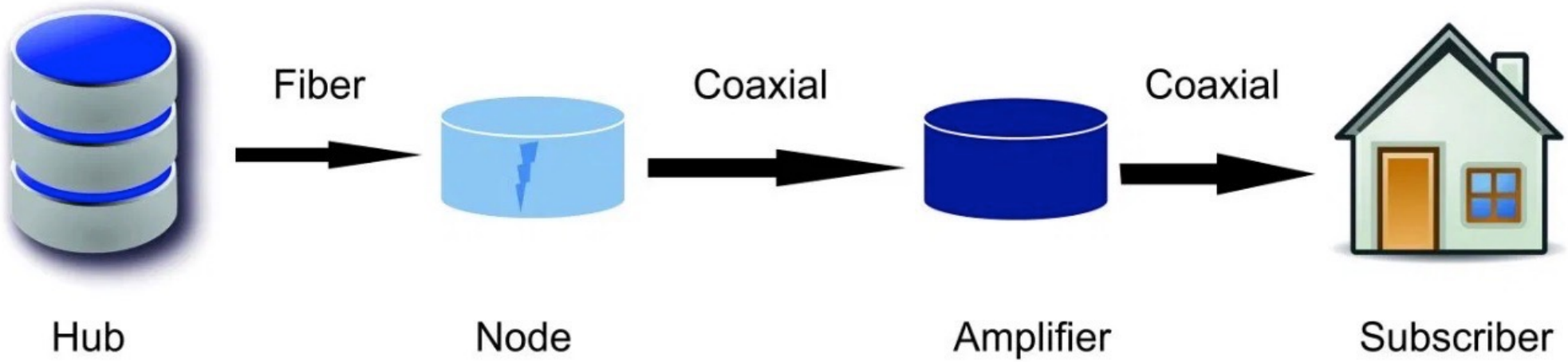


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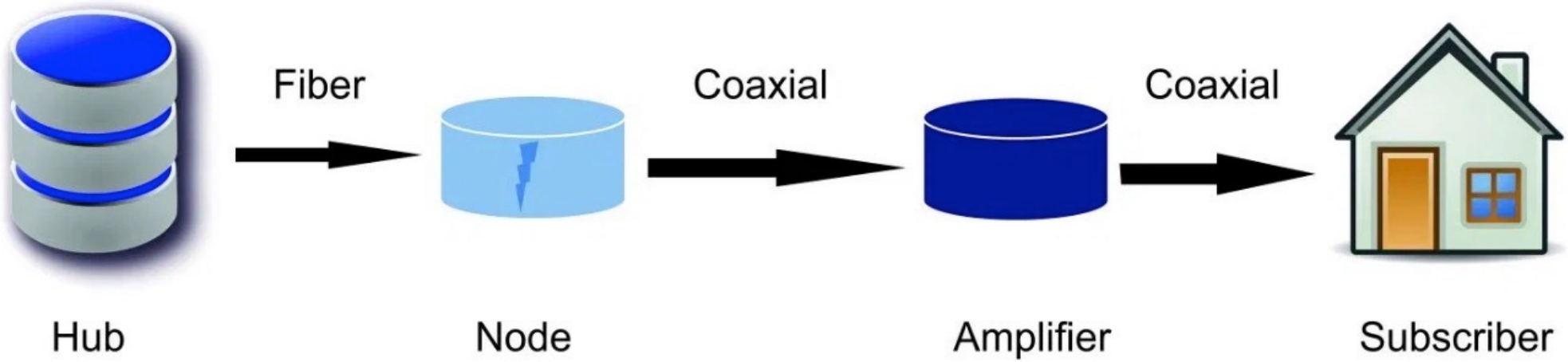


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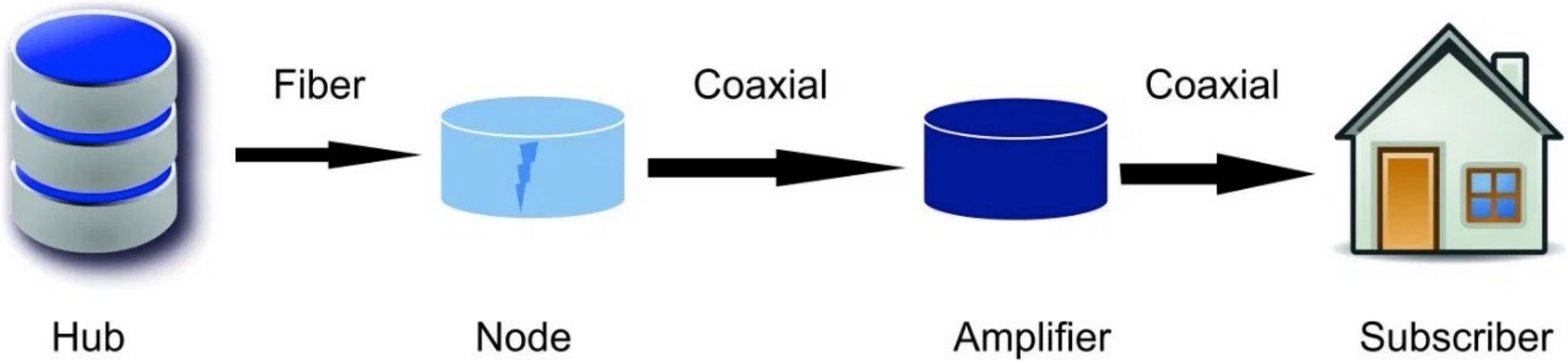


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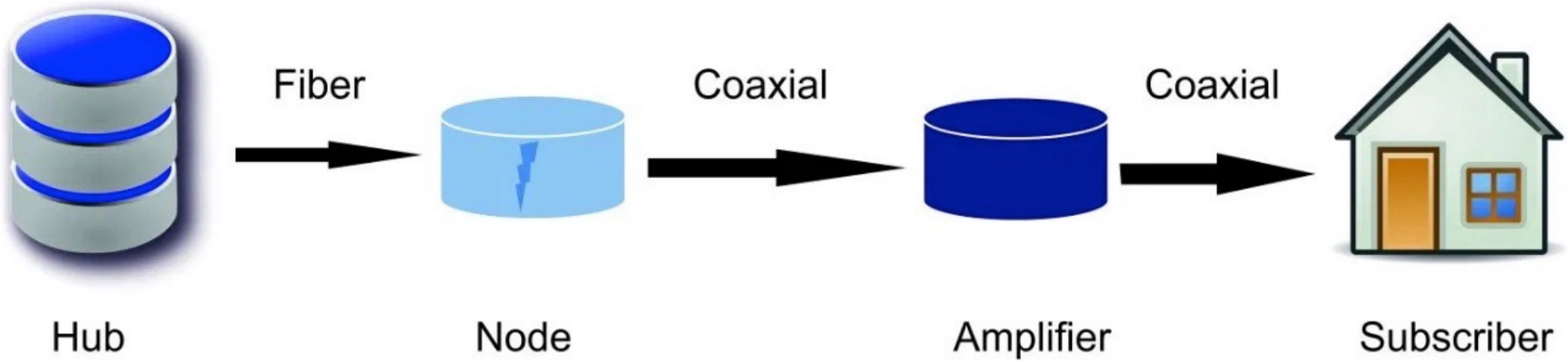


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- Aging can lead to problems
  - Cable shielding erosion
  - Loose connectors
  - Broken amplifiers
  - …
- Reliablity of broadband is at most 99% (<< FCC‘s requirement for PSTN, 99.99%)

# Goal

Improving the reliability of cable broadband networks

# Roadmap

- Limitations of Existing Work
- CableMon Design
  - High-level Idea
  - Challenges
  - Solutions
  - ISP Deployment
- Evaluation
- Conclusion

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# Proactive Network Maintenance (PNM)

**Cable Modem (CM)**

**Cable Modem Termination System (CMTS)**

- Cable industry developed the PNM framework
- CMTS communicates with CM periodically to obtain PNM data
- A monitoring server collects all CMs' PNM data
  - E.g., Signal to Noise Ratio (SNR)

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DOCSIS

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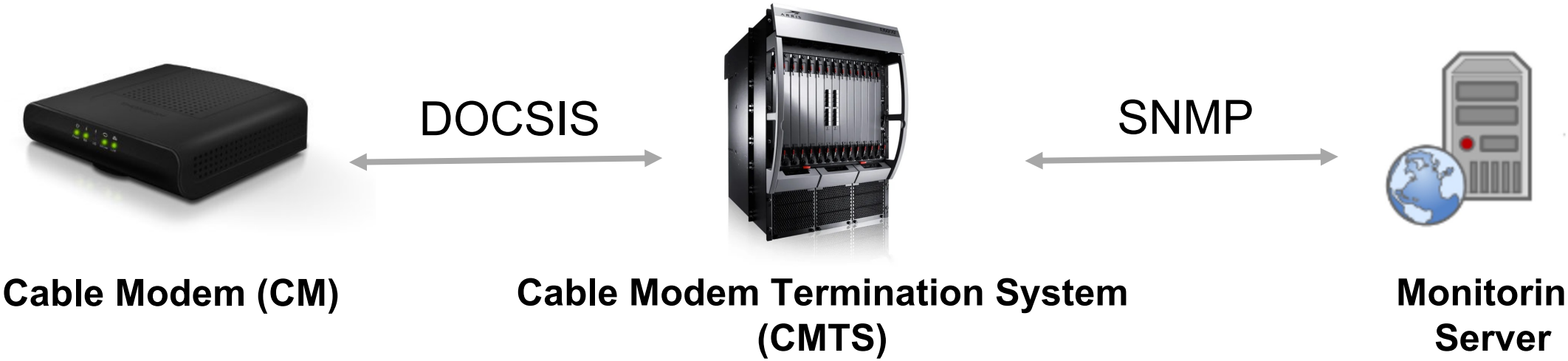


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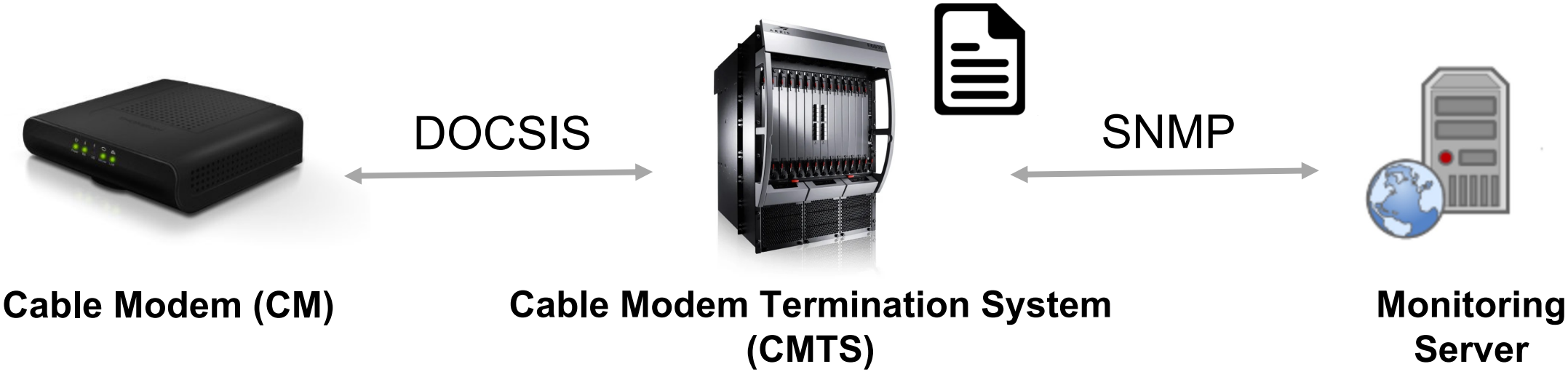


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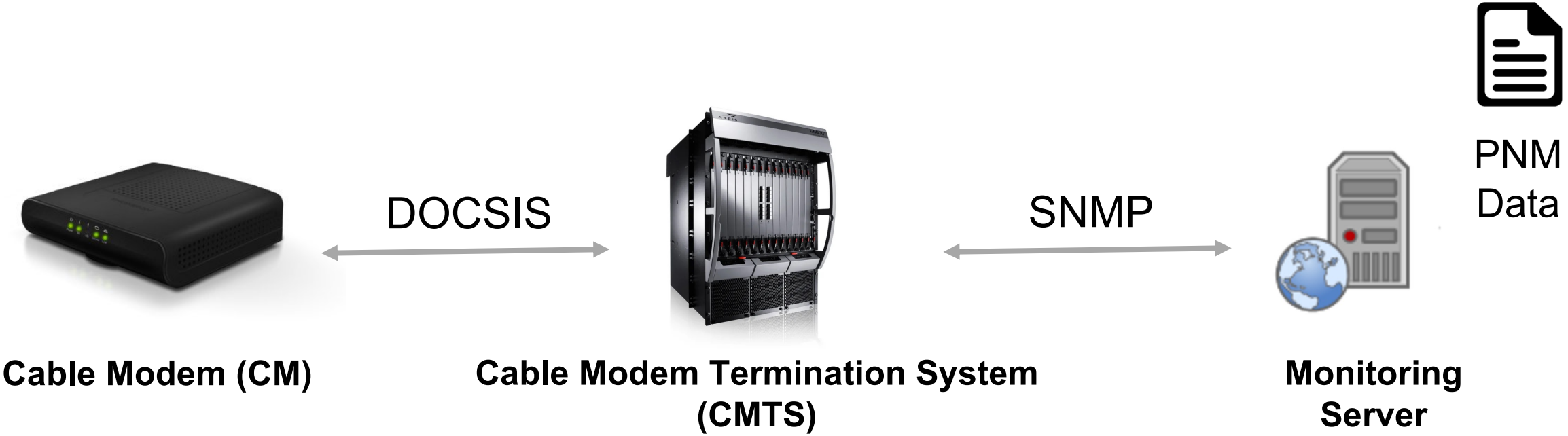


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# Existing Work

- Manually-set thresholds
  - A metric below/above a threshold: Repair the network
  - Hard to determine a proper threshold manually
  - Current recommendations: High false positives
    - In one of our studies, over 25% modems need repair following the PNM Best Practice document

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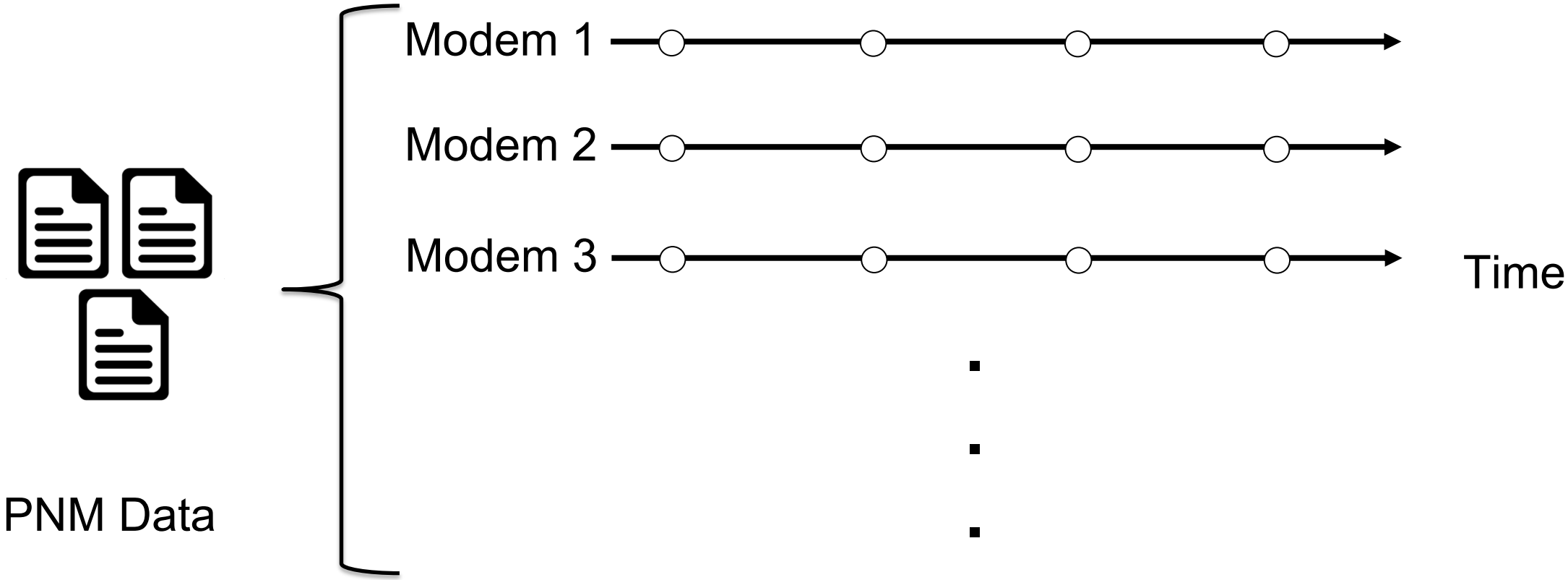
- Design goals
  - Save operational costs of ISPs by forecasting troubles before customer calls
  - No manual labeling
  - No extensive parameter tuning
  - Efficient

# Datasets: PNM Data and Customer Trouble Tickets



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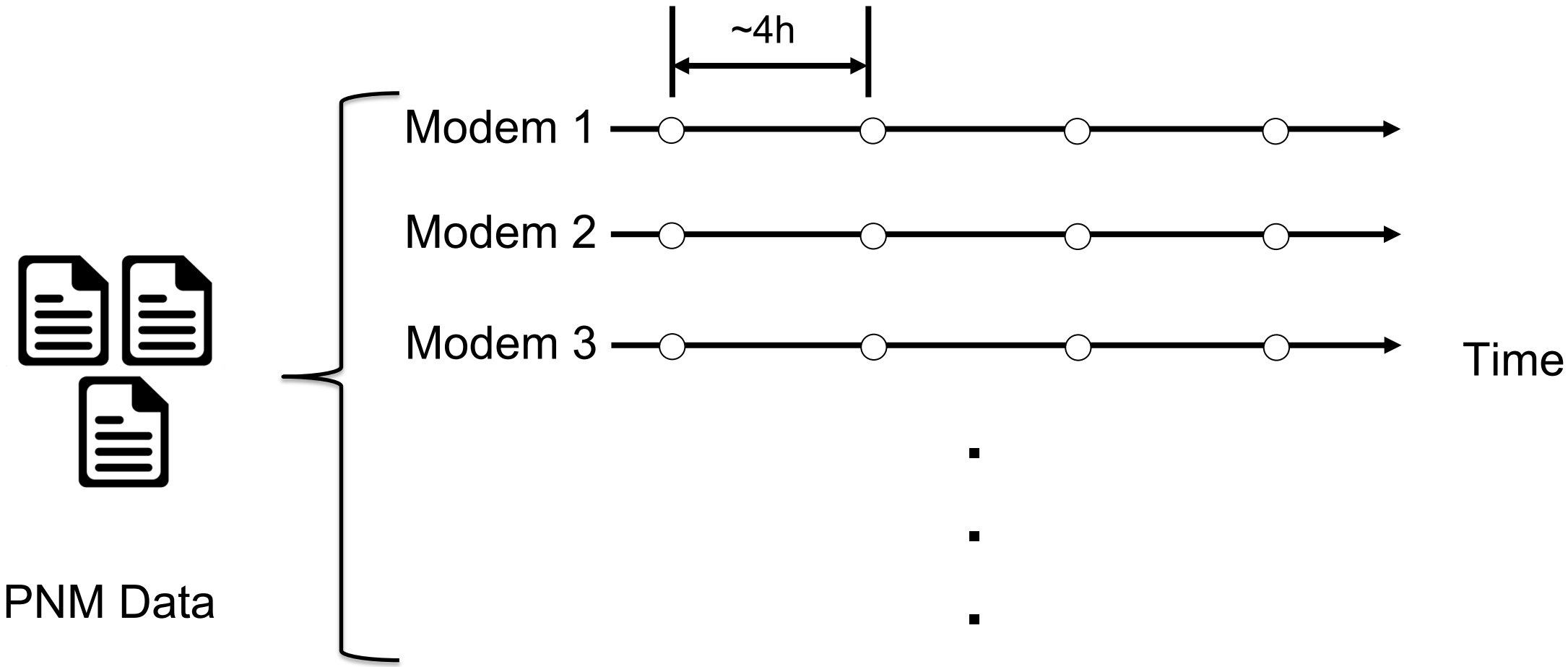

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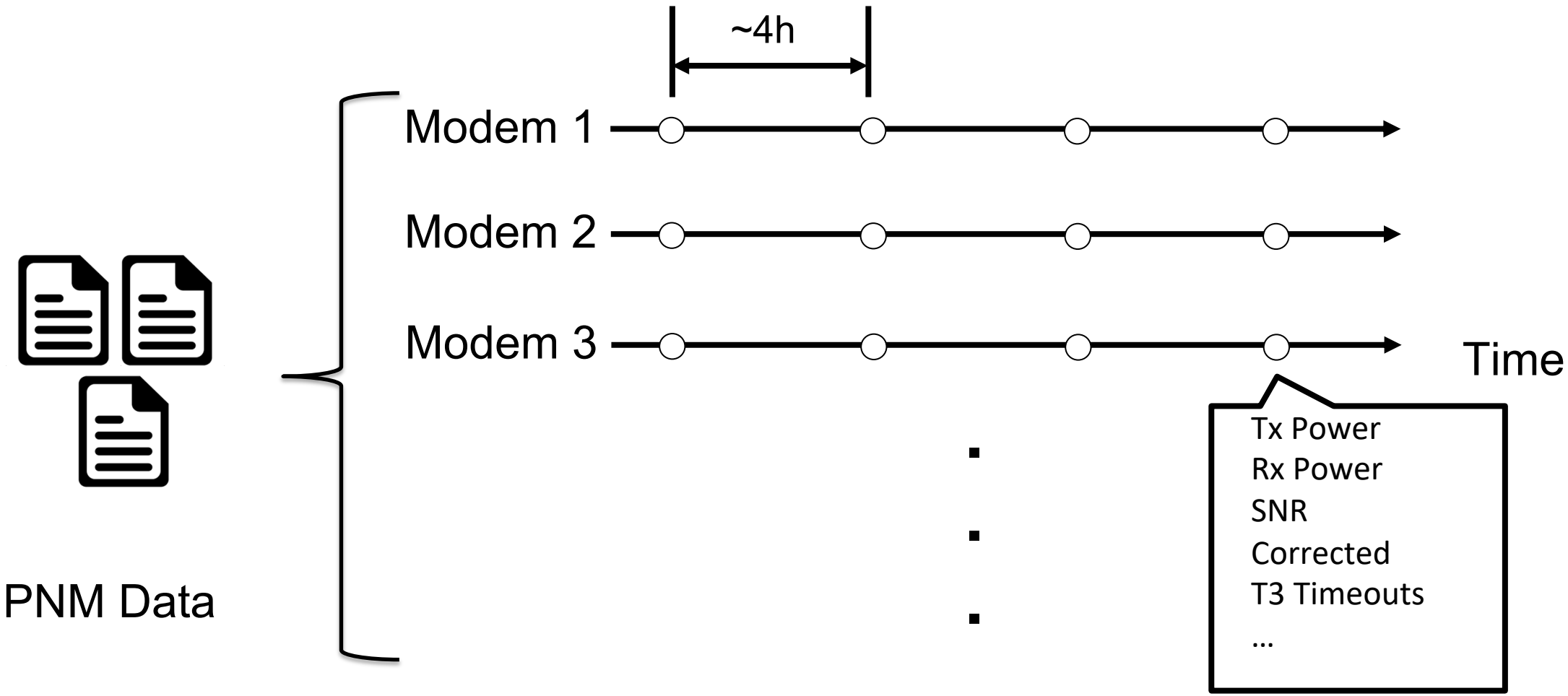

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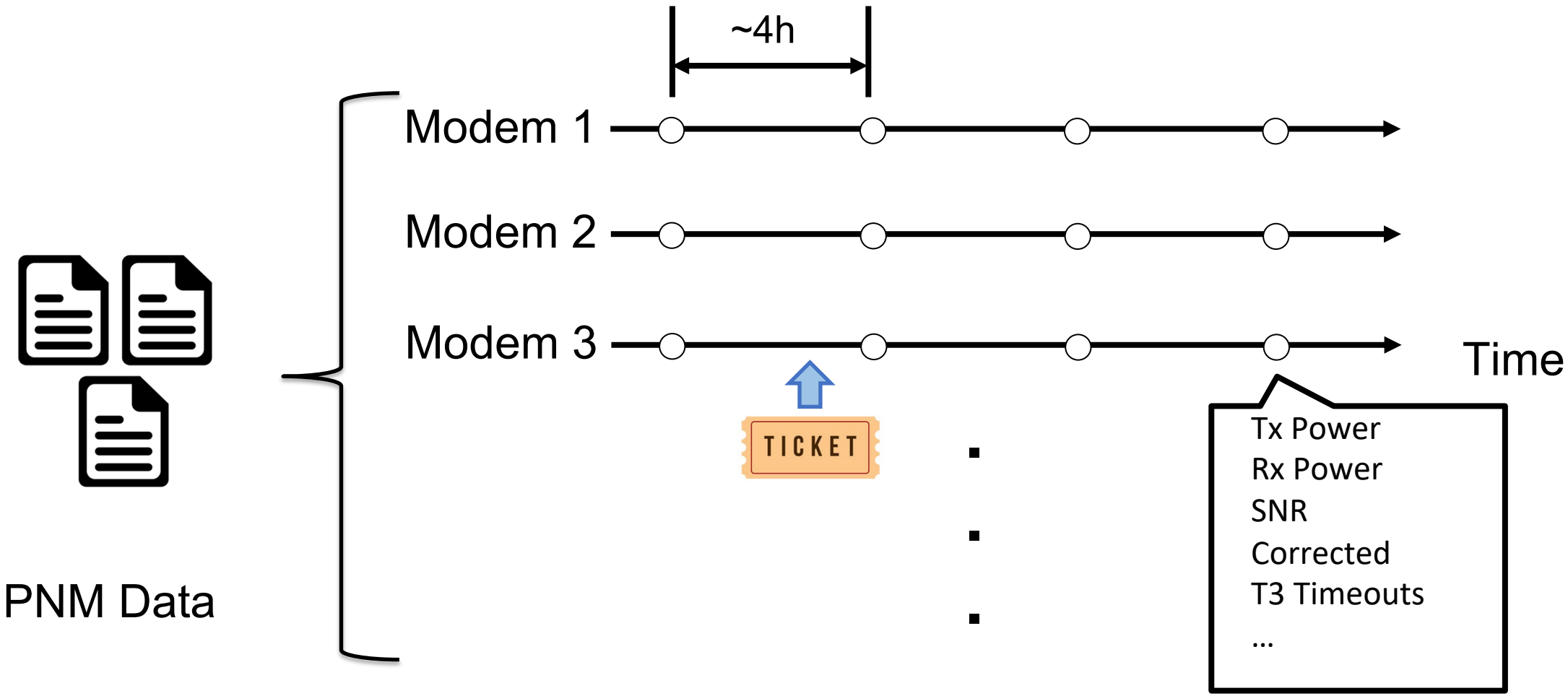

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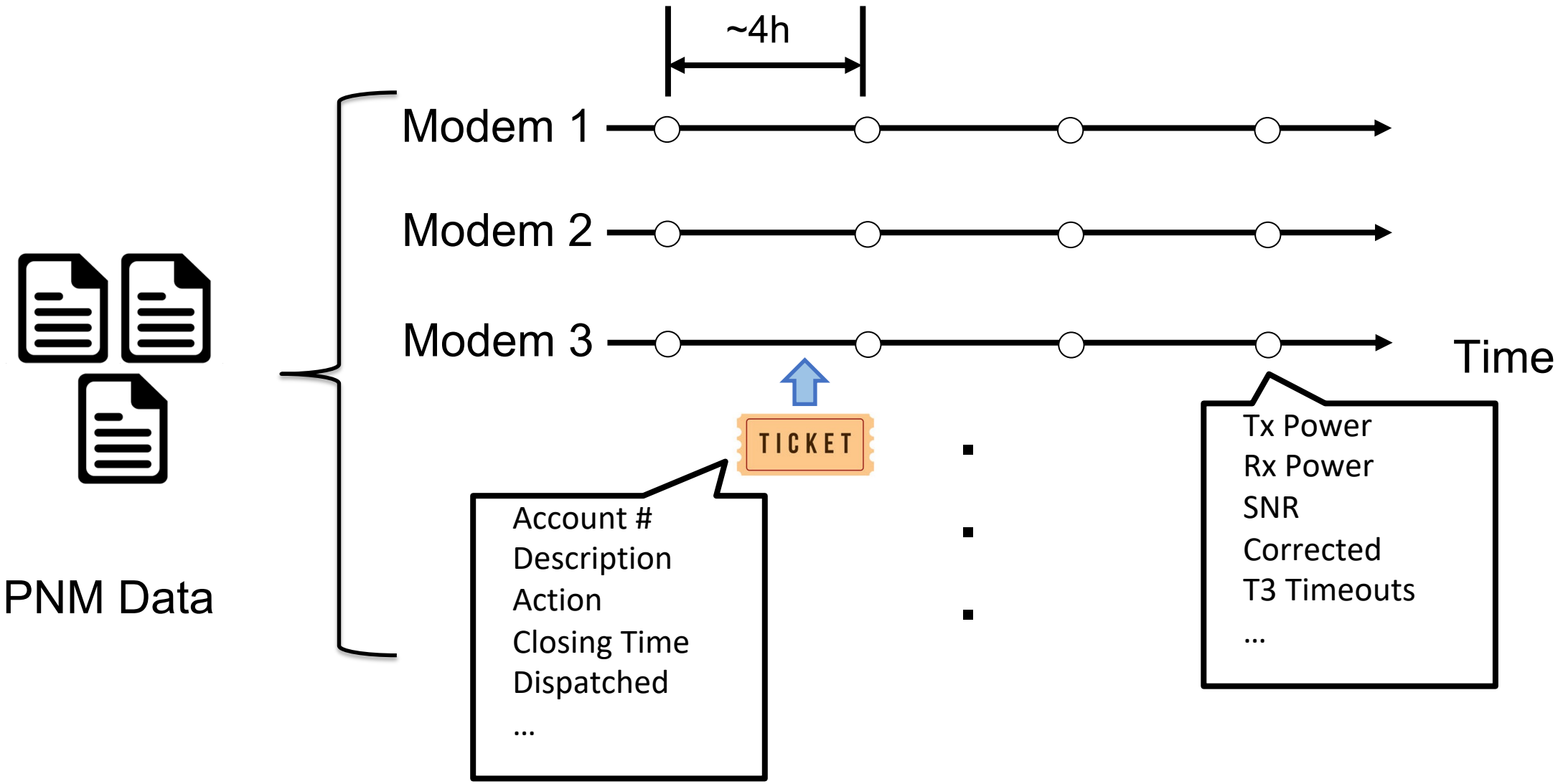
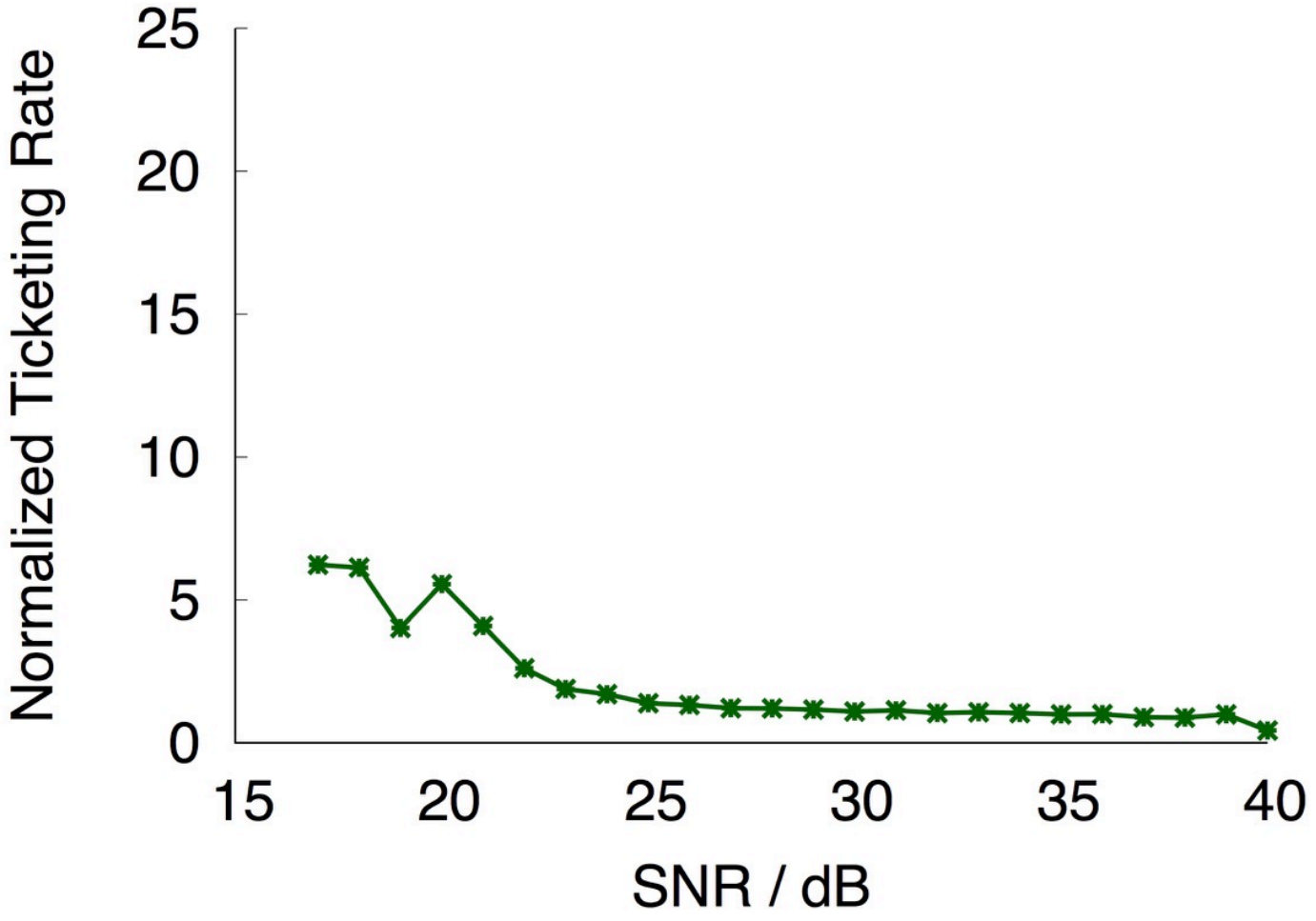


# Tickets Correlate with Network Faults

Ticketing Rate:

$$\frac{\text{\# of tickets}}{\text{time}}$$

Tickets: Hints to detect network faults



# Challenges

- Tickets are noisy
  - Customers may call for network-irrelevant issues
  - Customers may not call when network faults occur

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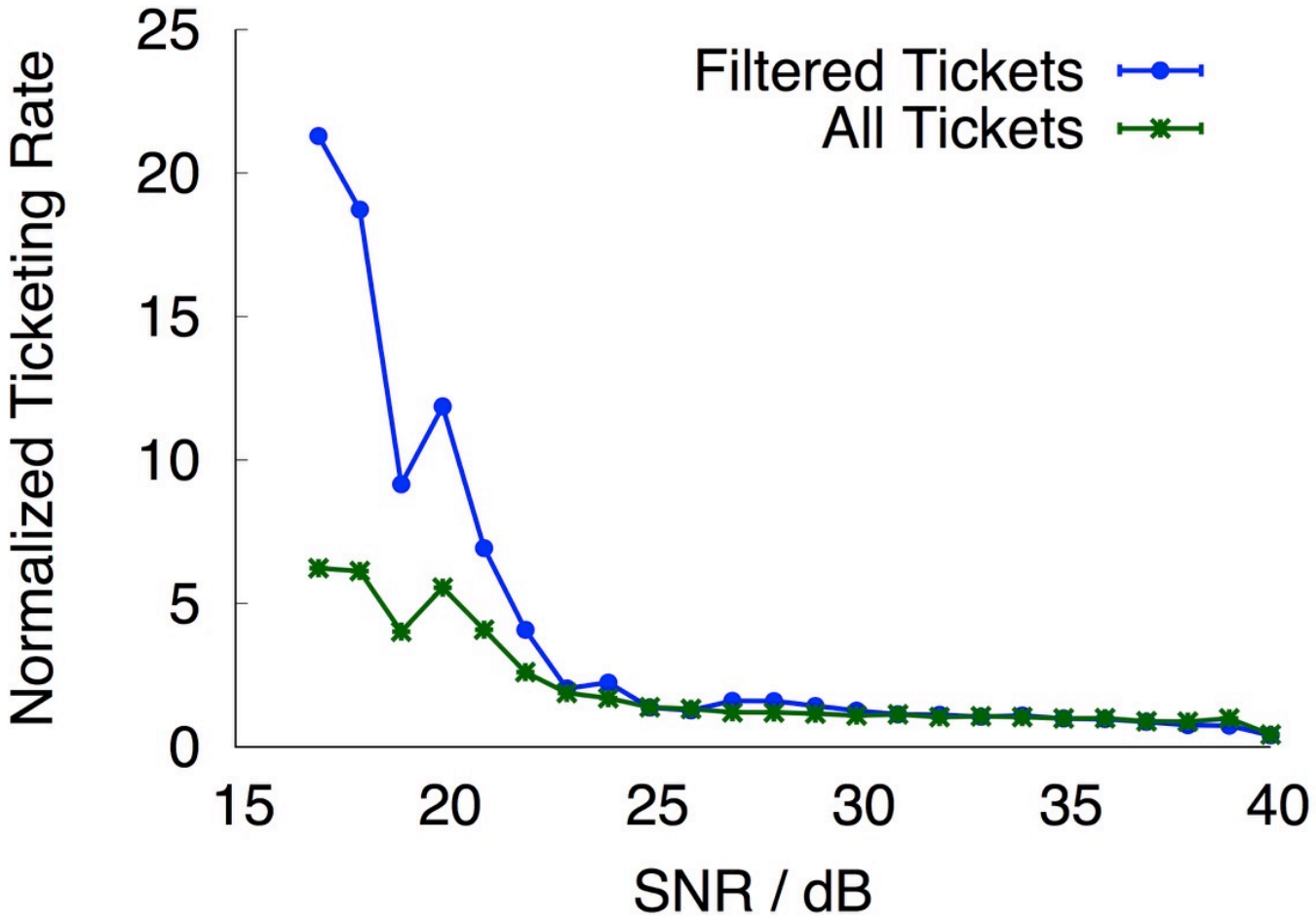
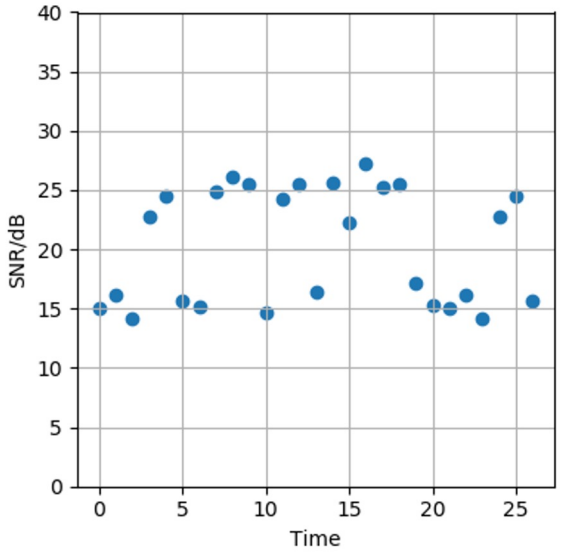
- PNM data
  - Instantaneous channel conditions, not sufficient for fault detection
  - Including environmental noise, not an accurate description of channel conditions

# Filter Non-network Related Tickets




- Tickets are filtered according to the Description, Action, Dispatched, etc.
- Network tickets correlate better with PNM data values

# Feature Generation



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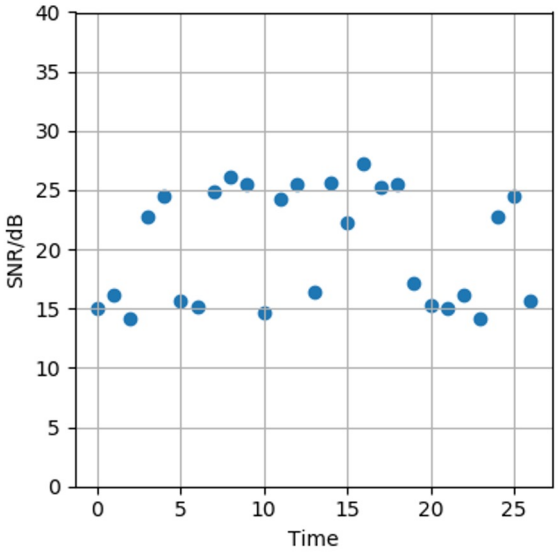


Statistical
Models

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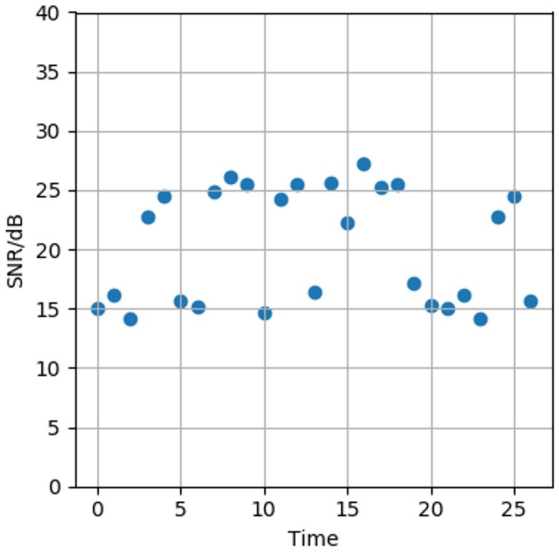
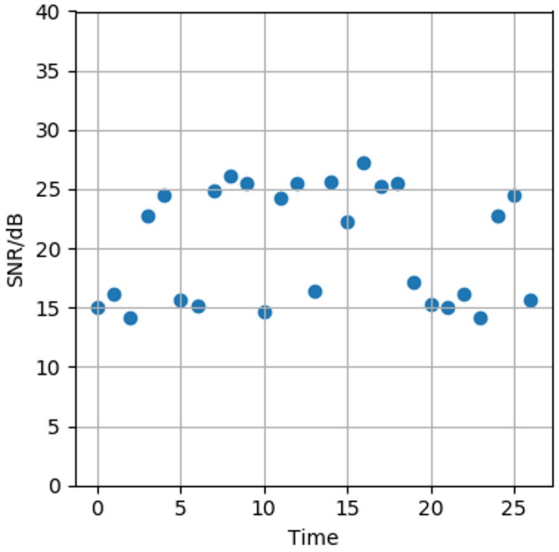



Statistical Models

$$\frac{V_i + V_{i-1} + \cdots + V_{i-win+1}}{win}$$

Moving Average

# Feature Generation

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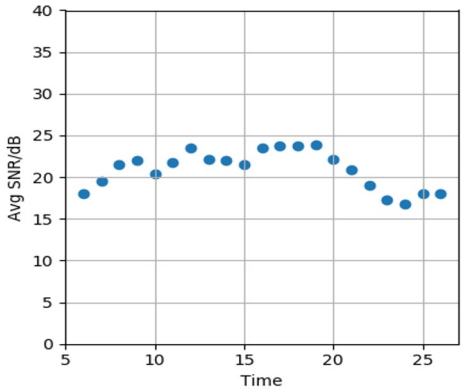


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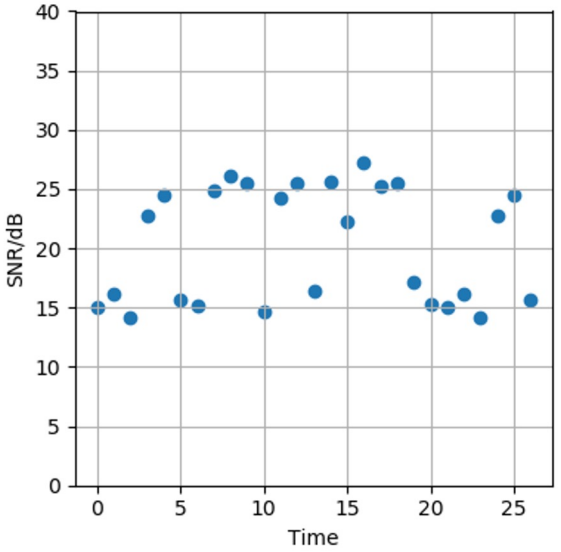


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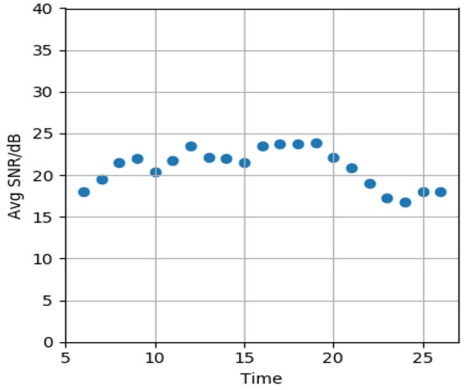


Moving Average

$$\frac{win \cdot V_i + (win-1) \cdot V_{i-1} + \cdots + 1 \cdot V_{i-win+1}}{win \cdot (win-1)/2}$$

Weighted MA

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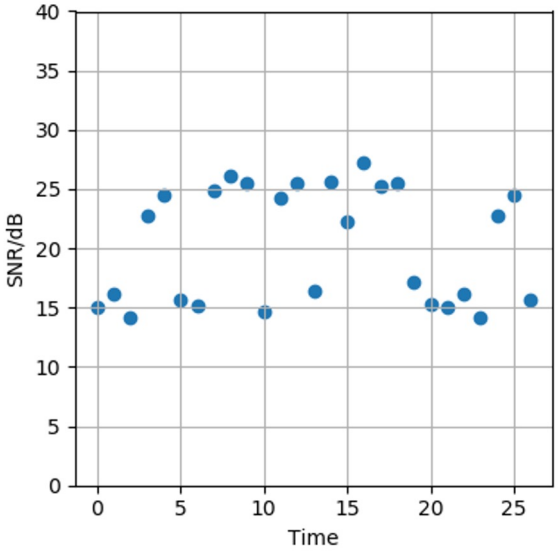


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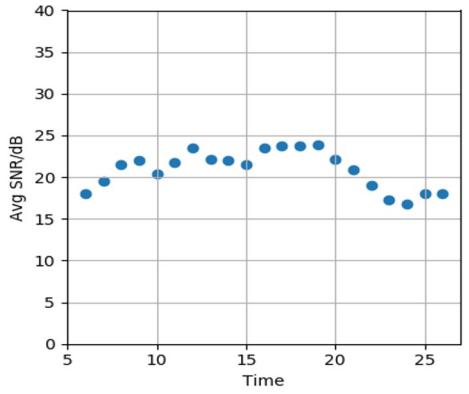


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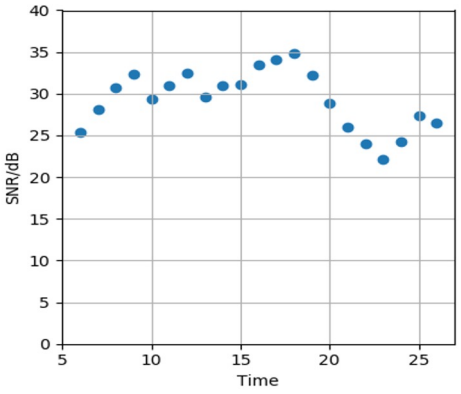


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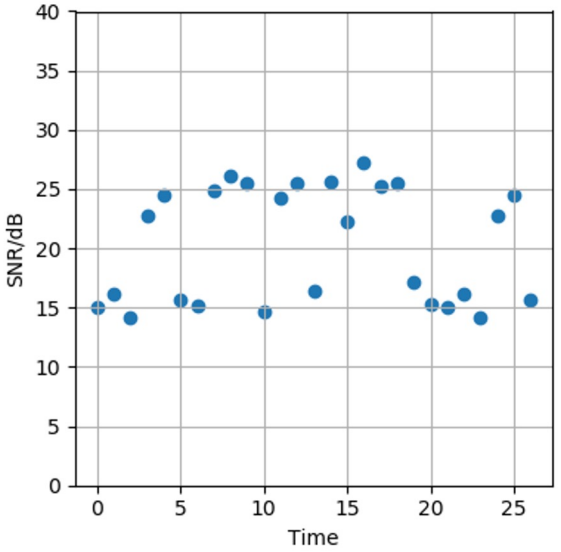


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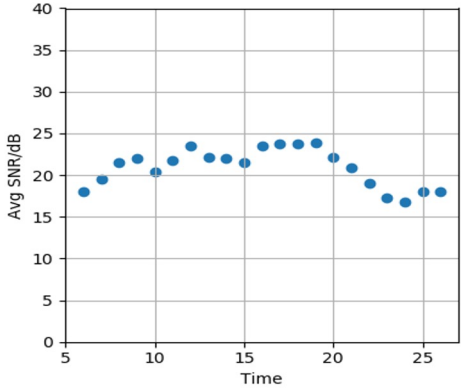


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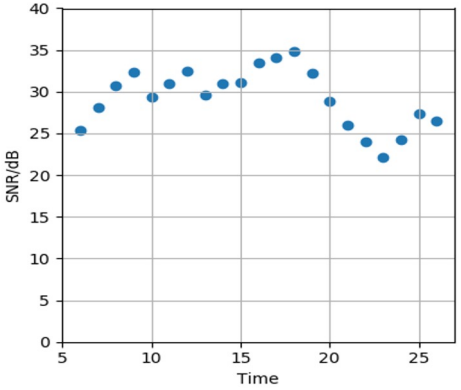


Weighted MA

$$V_i - WMA_i$$

WMA Difference

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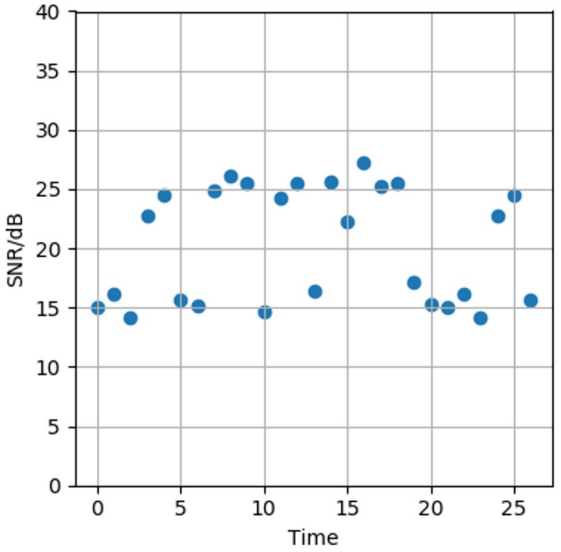


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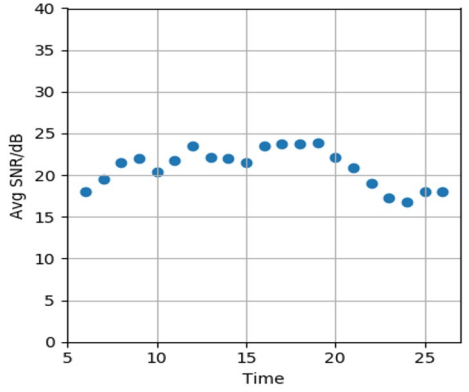


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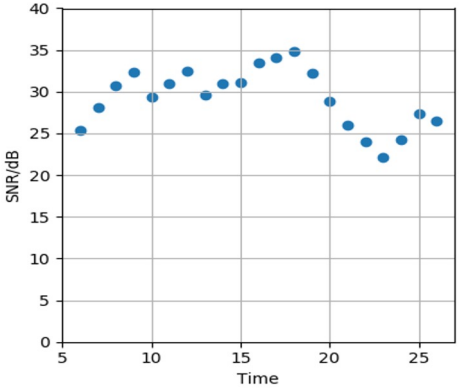


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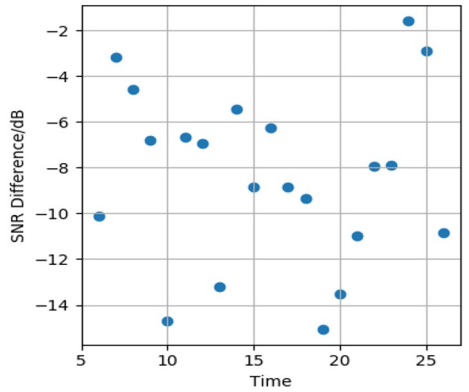


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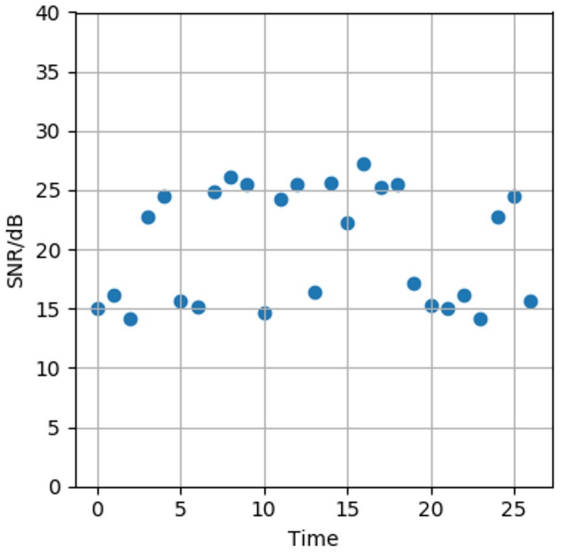


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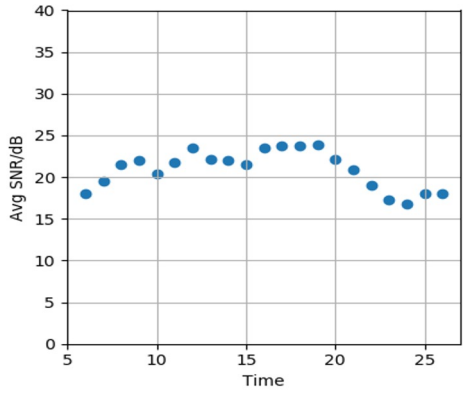


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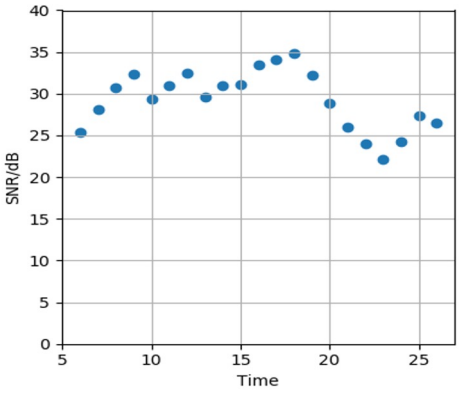


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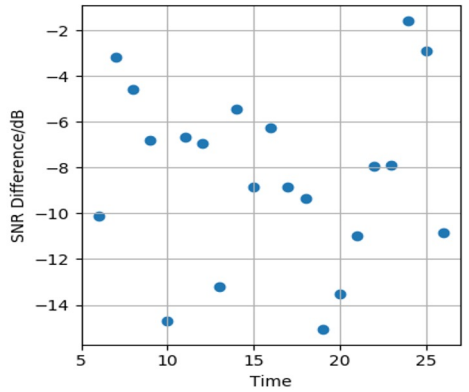


WMA Difference

$$\frac{1}{win}\sum_{k=i-win+1}^{i}(V_k - AVG_i)^2$$

Variance

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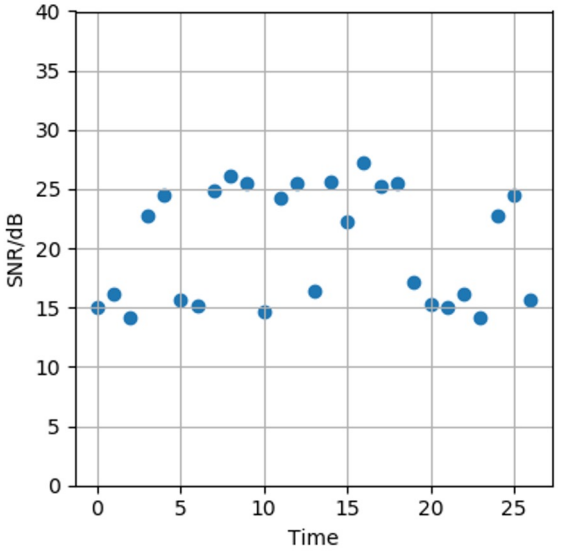


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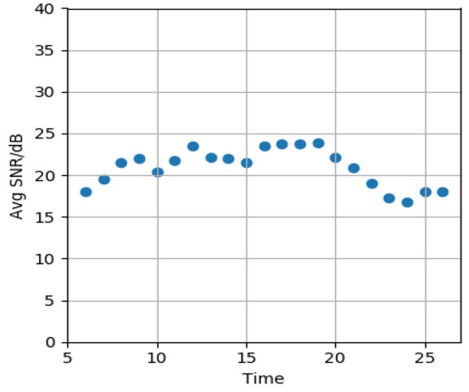


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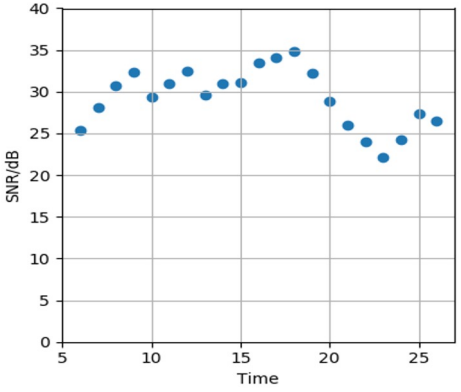


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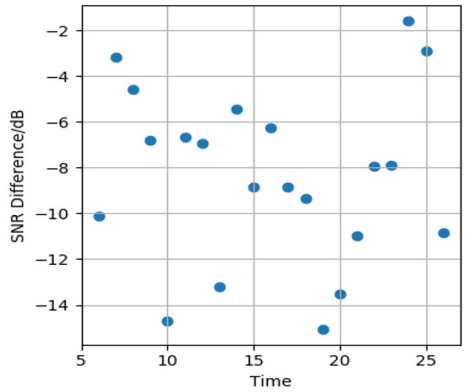


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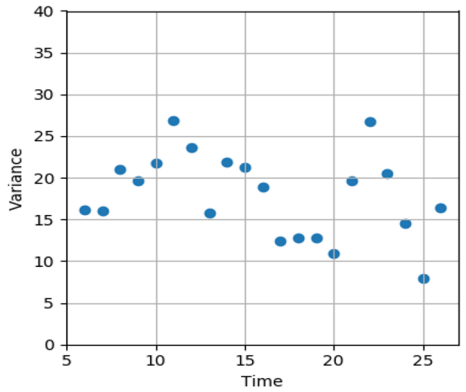
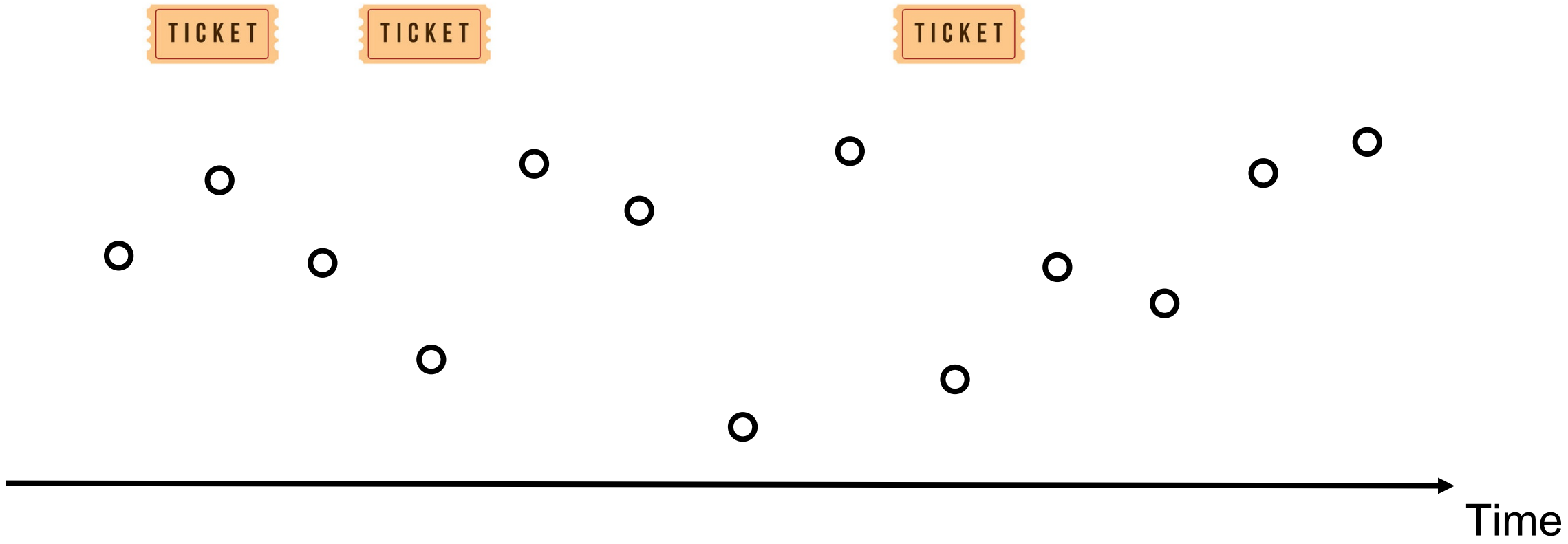



Variance

# Determine the Threshold



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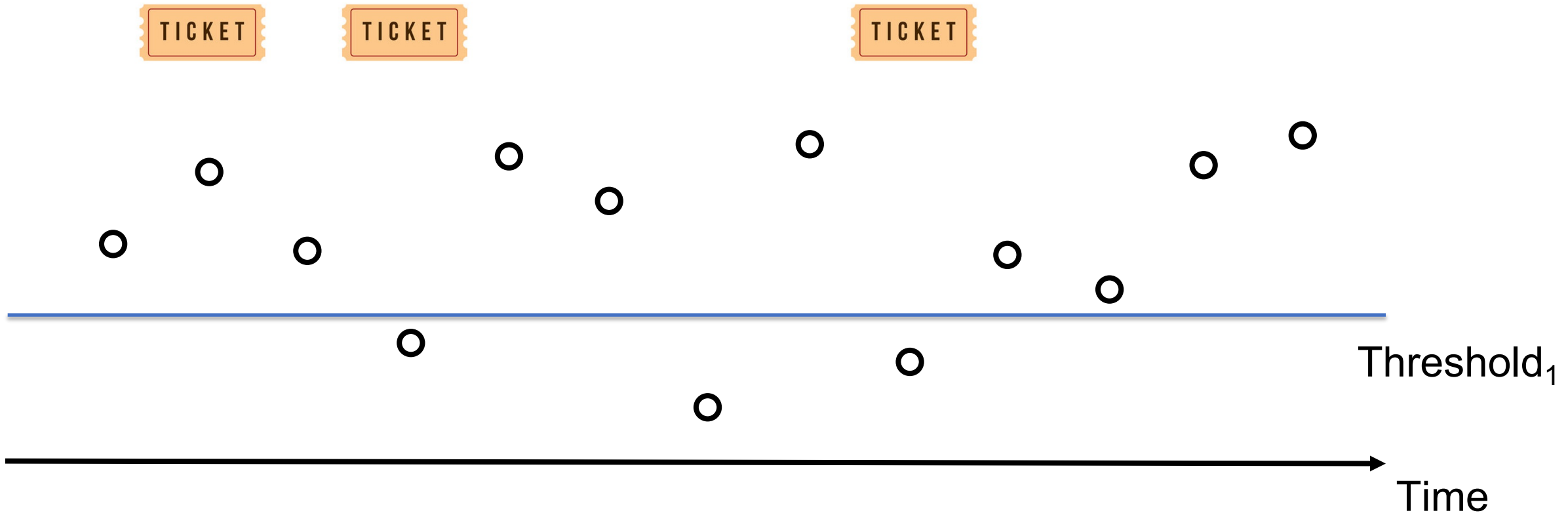

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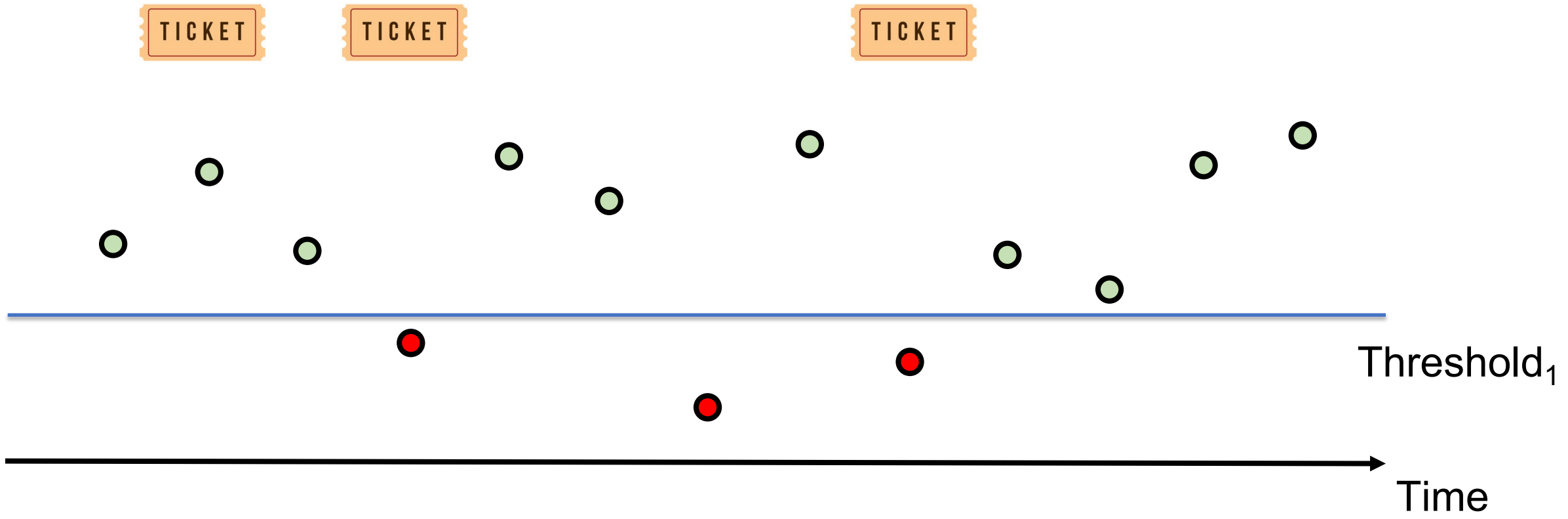

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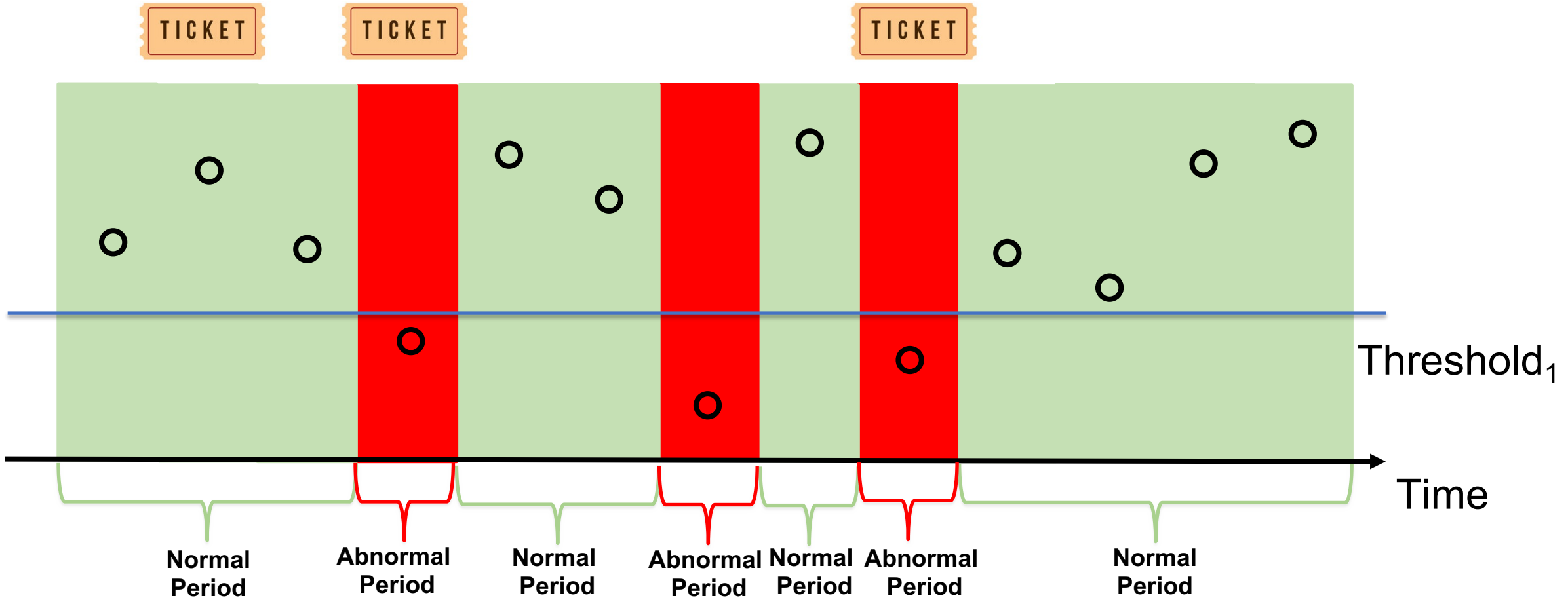

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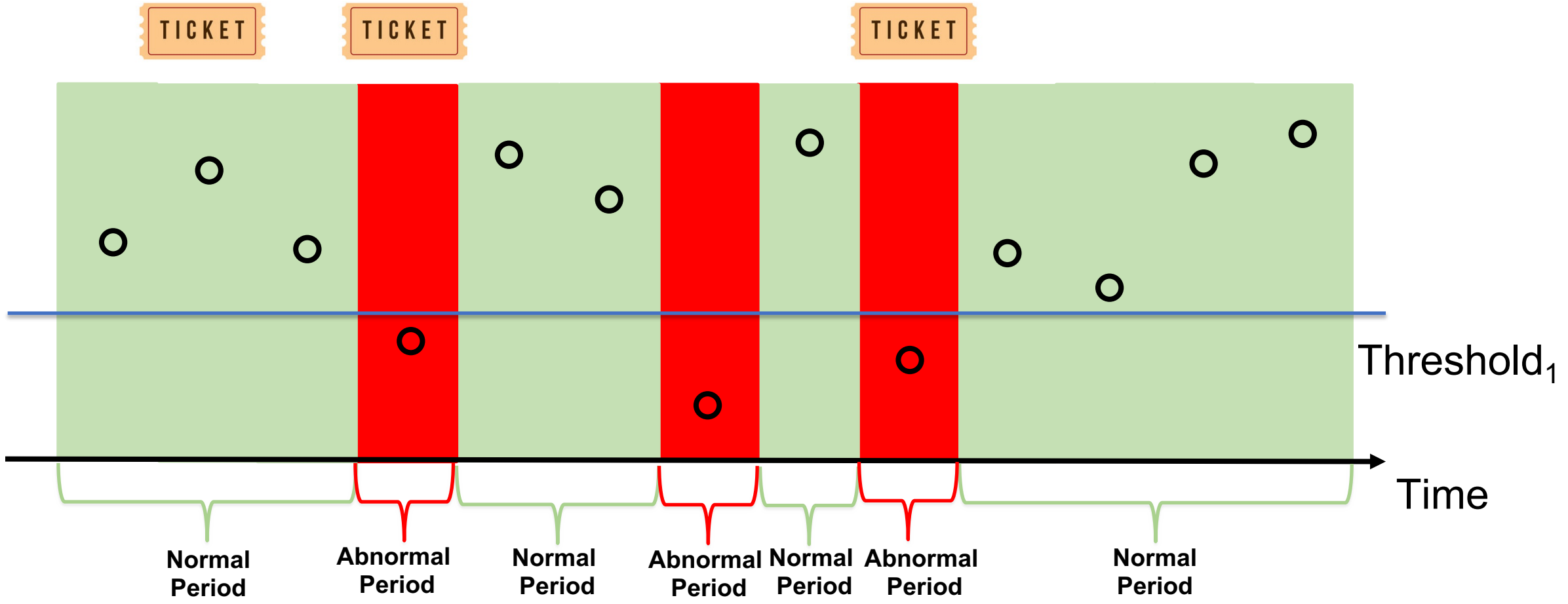


Normal:

- 1 ticket
- 10 data points (~40 hours)
- Ticketing Rate: 1/40 hours

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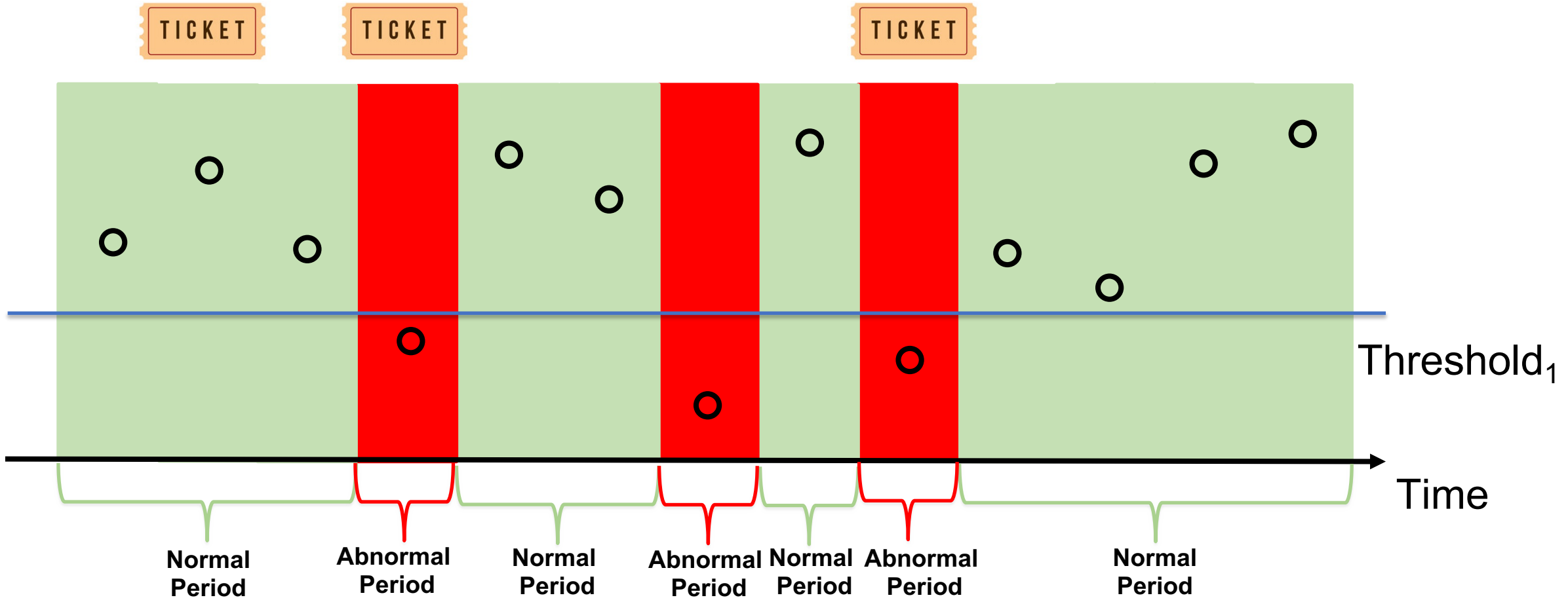


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- 3 data points (~12 hours)
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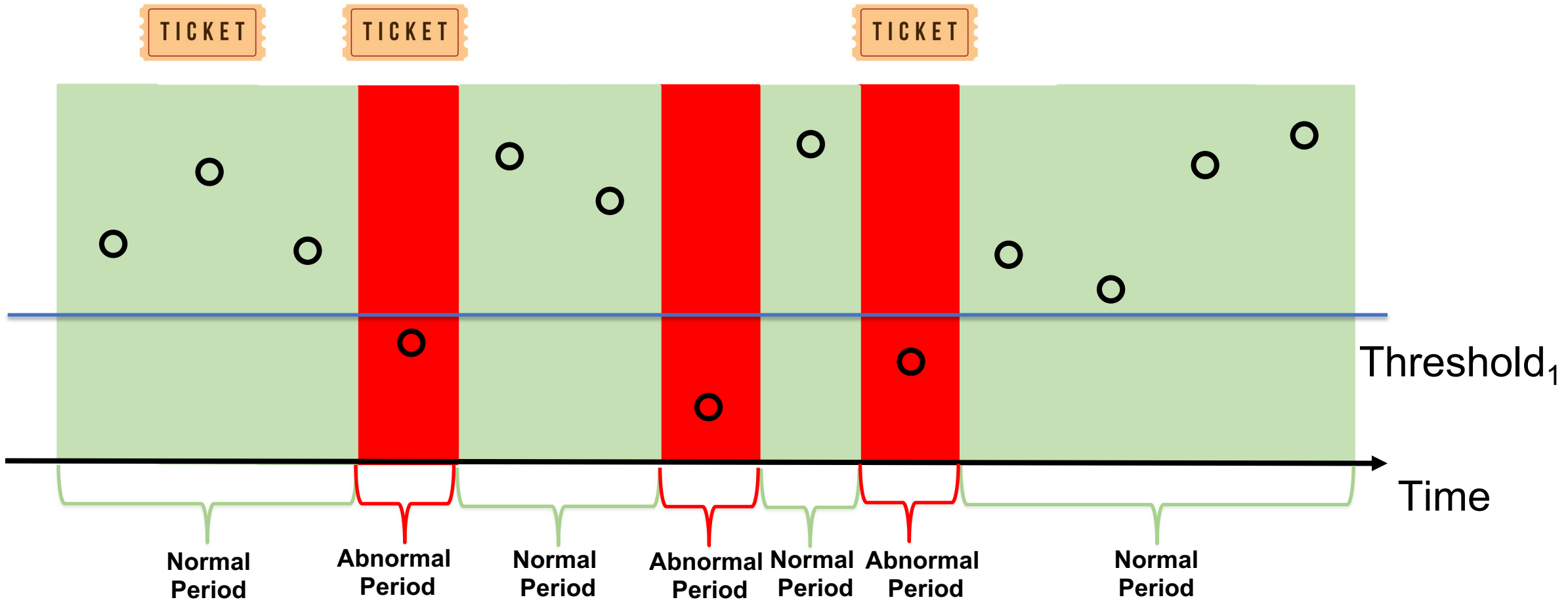
# Determine the Threshold

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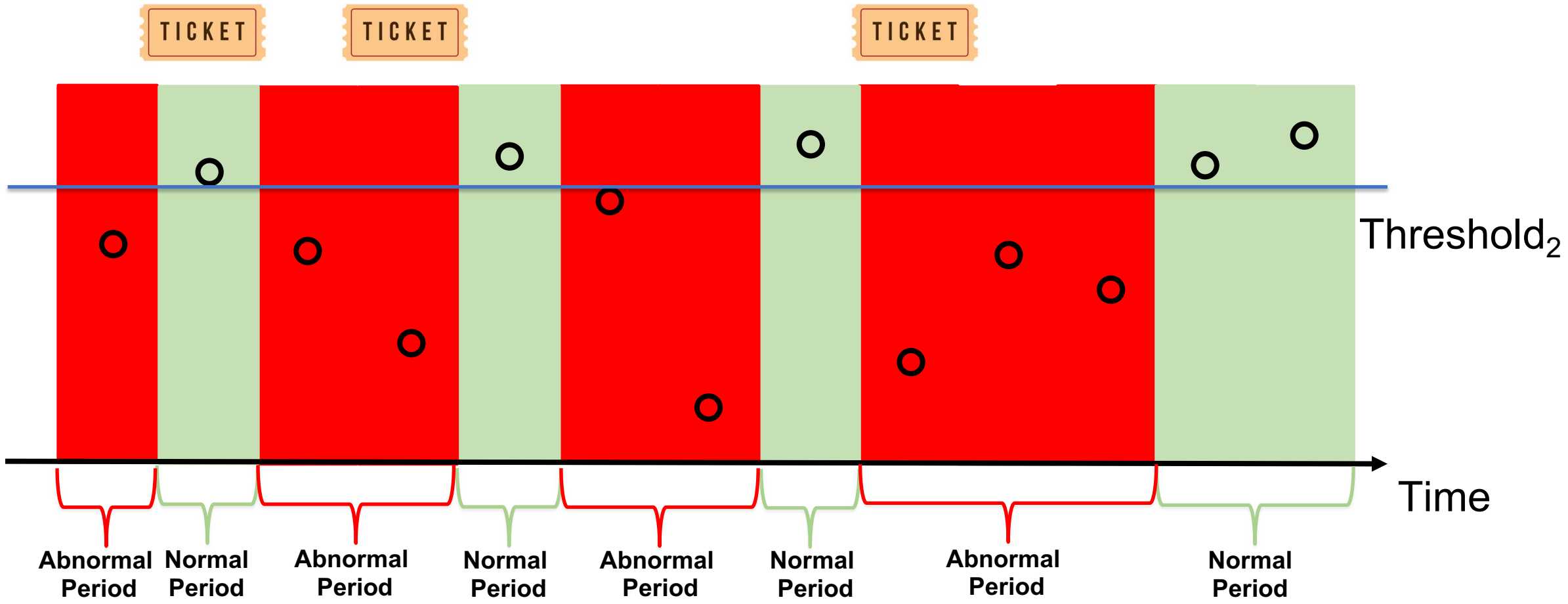
- 3 data points (~12 hours)
- Ticketing Rate: 2/12 hours

$$\text{Ticketing Rate Ratio} = \frac{\text{Abnormal Ticketing Rate}}{\text{Normal Ticketing Rate}} = 6.67$$

# Determine the Threshold



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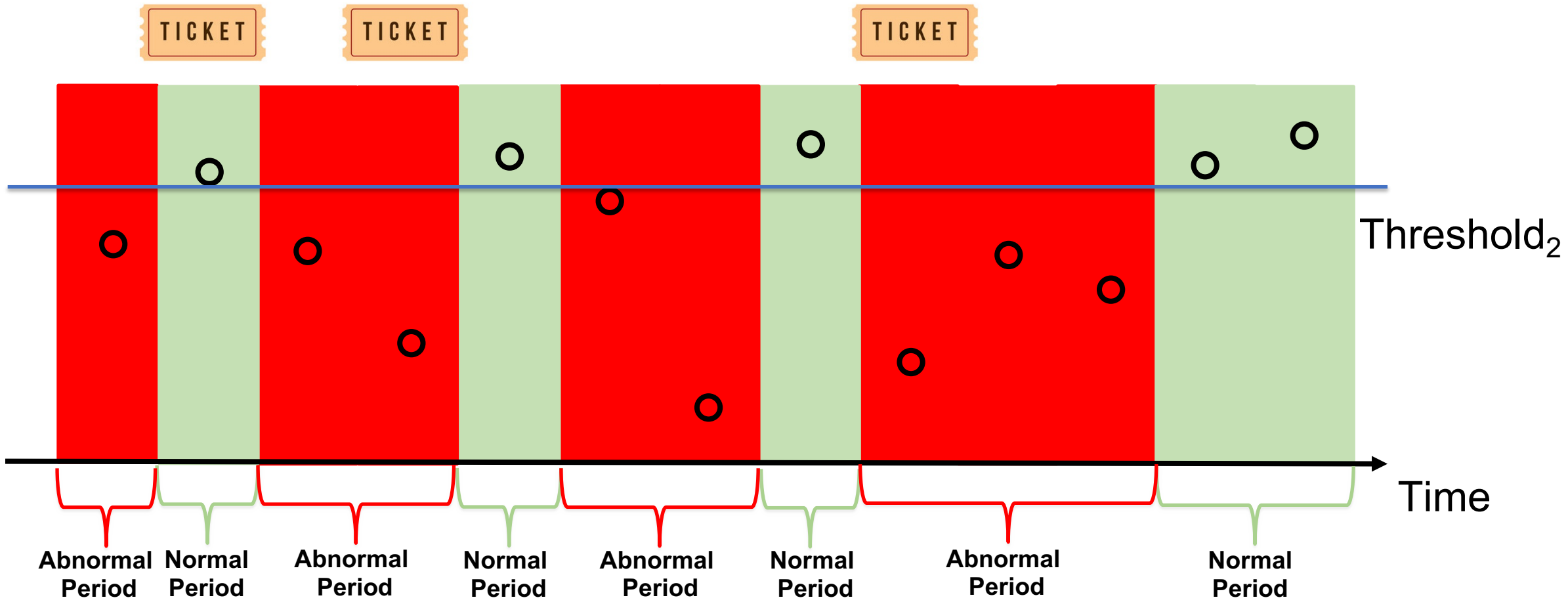
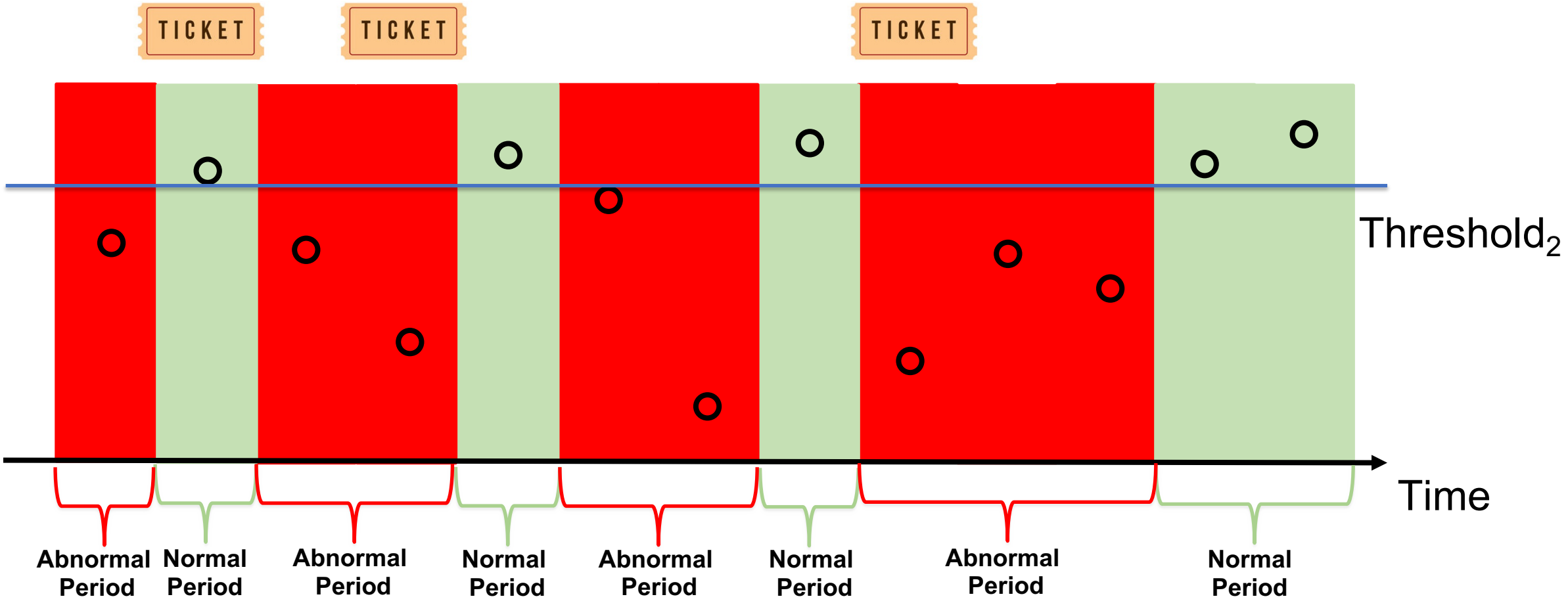



Normal:

- 1 ticket
- 5 data points (~20 hours)
- Ticketing Rate: 1/20 hours

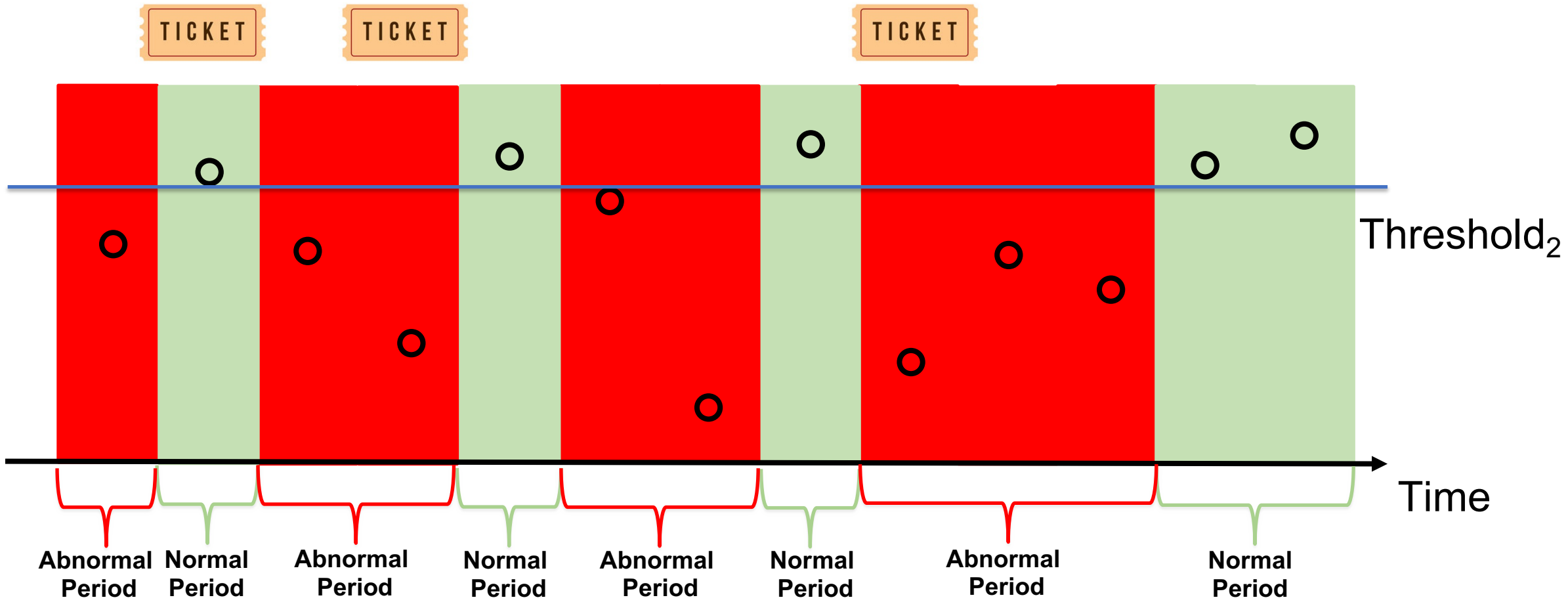
# Determine the Threshold




Normal:
- 1 ticket
- 5 data points (~20 hours)
- Ticketing Rate: 1/20 hours

Abnormal:
- 2 tickets
- 8 data points (~32 hours)
- Ticketing Rate: 2/32 hours

# Determine the Threshold

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- 8 data points (~32 hours)
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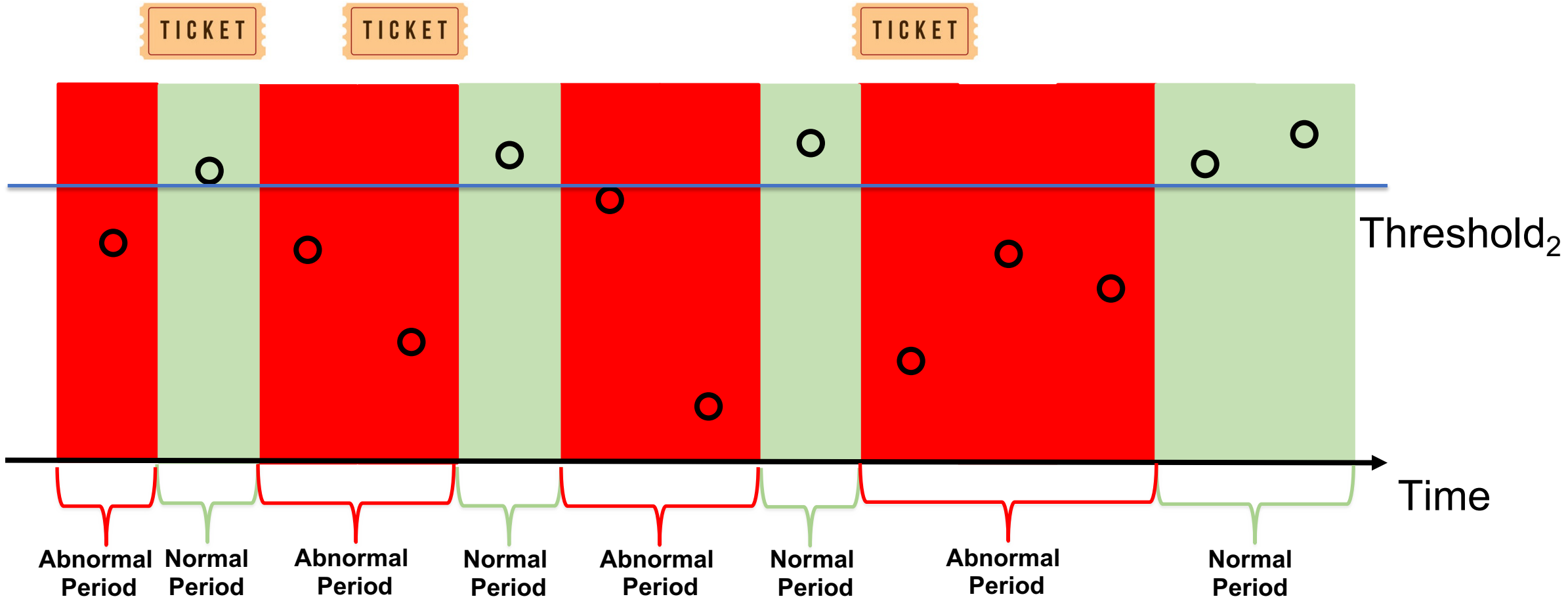
$$\text{Ticketing Rate Ratio} = \frac{\text{Abnormal ticketing rate}}{\text{Normal ticketing rate}} = 1.25$$

# Determine the Threshold




Threshold =
Argmax(Ticketing Rate Ratio)

$$\text{Ticketing Rate Ratio} = \frac{\text{Abnormal ticketing rate}}{\text{Normal ticketing rate}}$$

# CableMon Properties

- Ticketing Rate Ratio (TRR)

  1. is monotonously decreasing w.r.t. both false positives (FPs) and false negatives (FNs) under the assumption ticketing noise is uniformly distributed

  2. is maximized iff. both FPs and FNs are 0

**Formal proof can be found in the paper**

# Selecting Top Features

- We select the features that achieve the highest ticketing rate ratio
- For the features generated from the same metric, we will select at most two

# Top Five Features

| Feature | Ticketing Rate Ratio |
|---|---|
| snr-var | 14.49 |
| uncorrected-var | 7.66 |
| rxpower-wma-diff | 5.31 |
| t3timeouts-wma-diff | 4.93 |
| t4timeouts-var | 4.18 |

# Combining Features

- If one feature is abnormal, the data point is labelled as abnormal
  - Different features may detect different types of network faults
  - Use the threshold(s) that maximize(s) the ticketing rate ratio for each feature

# How ISPs Use CableMon

- Proactive detection
  - Make a dispatch decision only after a fault persists
  - Convert pointwise detection to abnormal event detection using a sliding window algorithm
    - See paper for more details

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- Diagnosis
  - Determine whether the customer reported problem is network relevant

# Roadmap

- Limitations of Existing Work
- CableMon Design
  - High-level Idea
  - Challenges
  - Solutions
  - ISP Deployment
- Evaluation
- Conclusion

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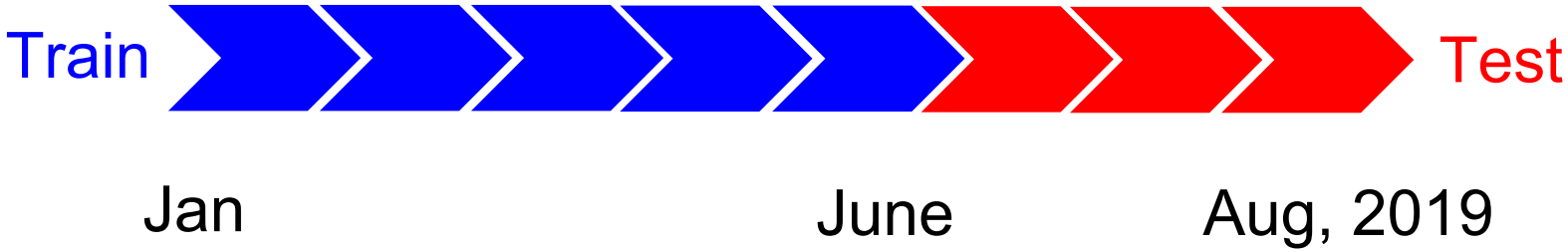
# Evaluation

- Dataset



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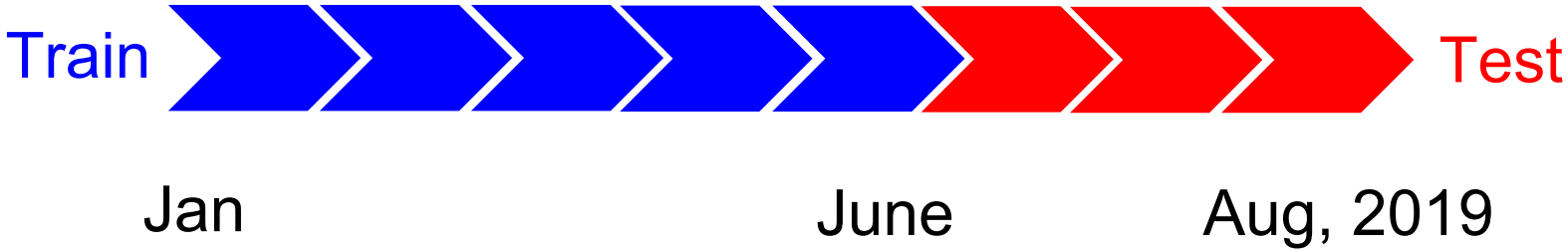


- Other Approaches

# Evaluation

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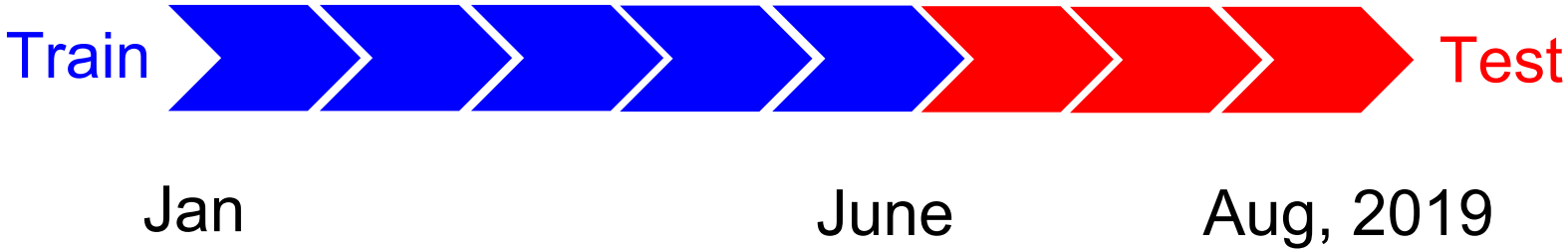


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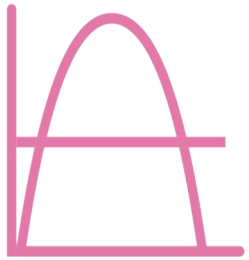
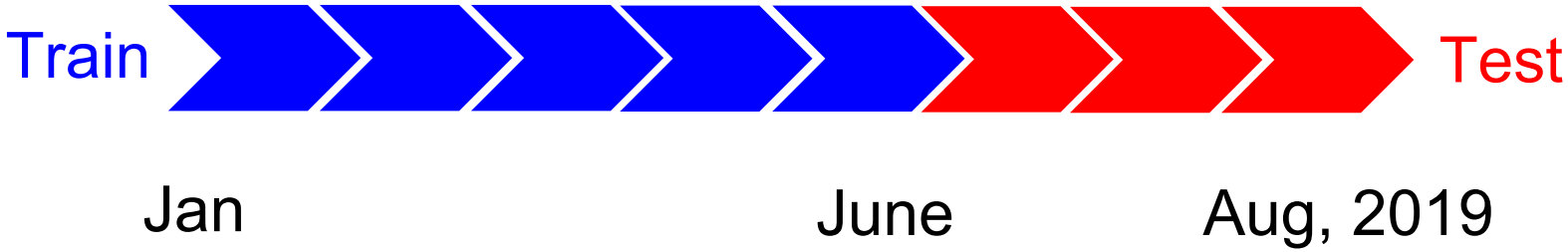


ISP Tools

# Evaluation

- Dataset

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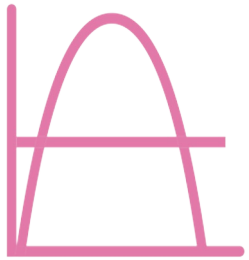

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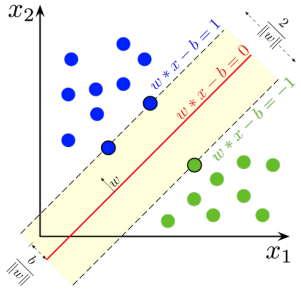
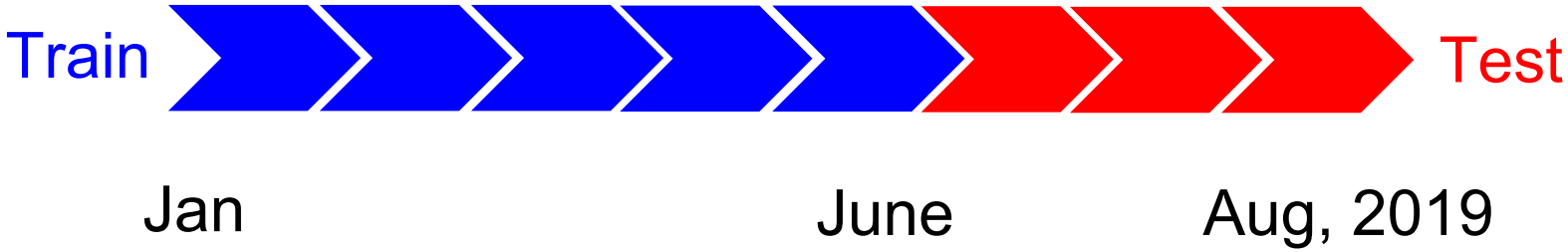



SVM

# Evaluation

- Dataset

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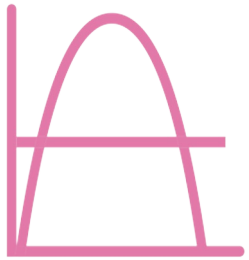

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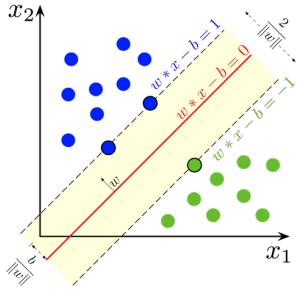


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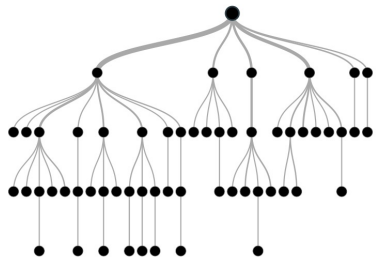
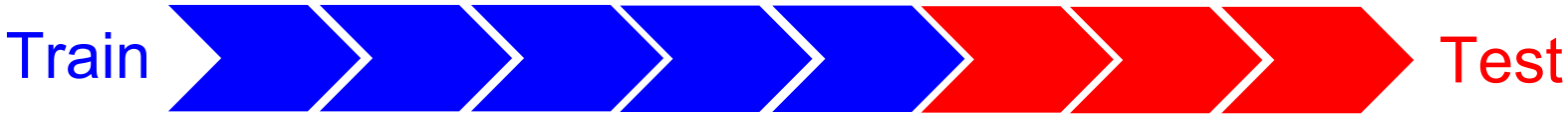


Decision Tree

# Evaluation

- Dataset




Jan June Aug, 2019

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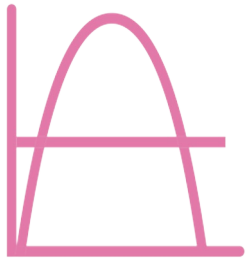

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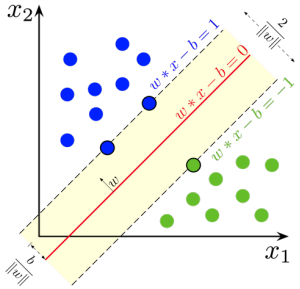


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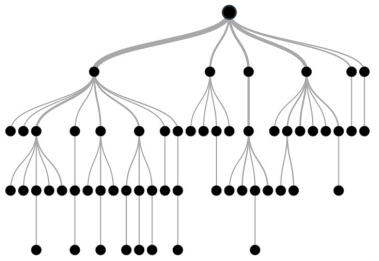

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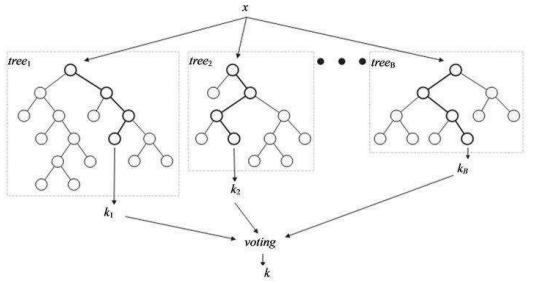


Random Forest

# Evaluation

- Methodology
  - Ideal: Real world deployment (working in progress)
  - Experiments: Emulate how ISPs use CableMon
    - Run the sliding window algorithm
    - Count the number of tickets arrived during an abnormal event

- Metrics
  - Ticket prediction accuracy
  - Ticket coverage
  - Normalized ticketing rate

# Results

| | Ticket Prediction Accuracy | Ticket Coverage | Normalized Ticketing Rate |
|---|---|---|---|
| CableMon | 81.92% | 22.99% | 3.55 |
| SVM | 75.64% | 12.54% | 2.02 |
| Random Forest | 73.14% | 14.21% | 2.24 |
| Decision Tree | 68.93% | 15.53% | 2.52 |
| Comcast's Tool | 23.48% | 2.21% | 1.18 |
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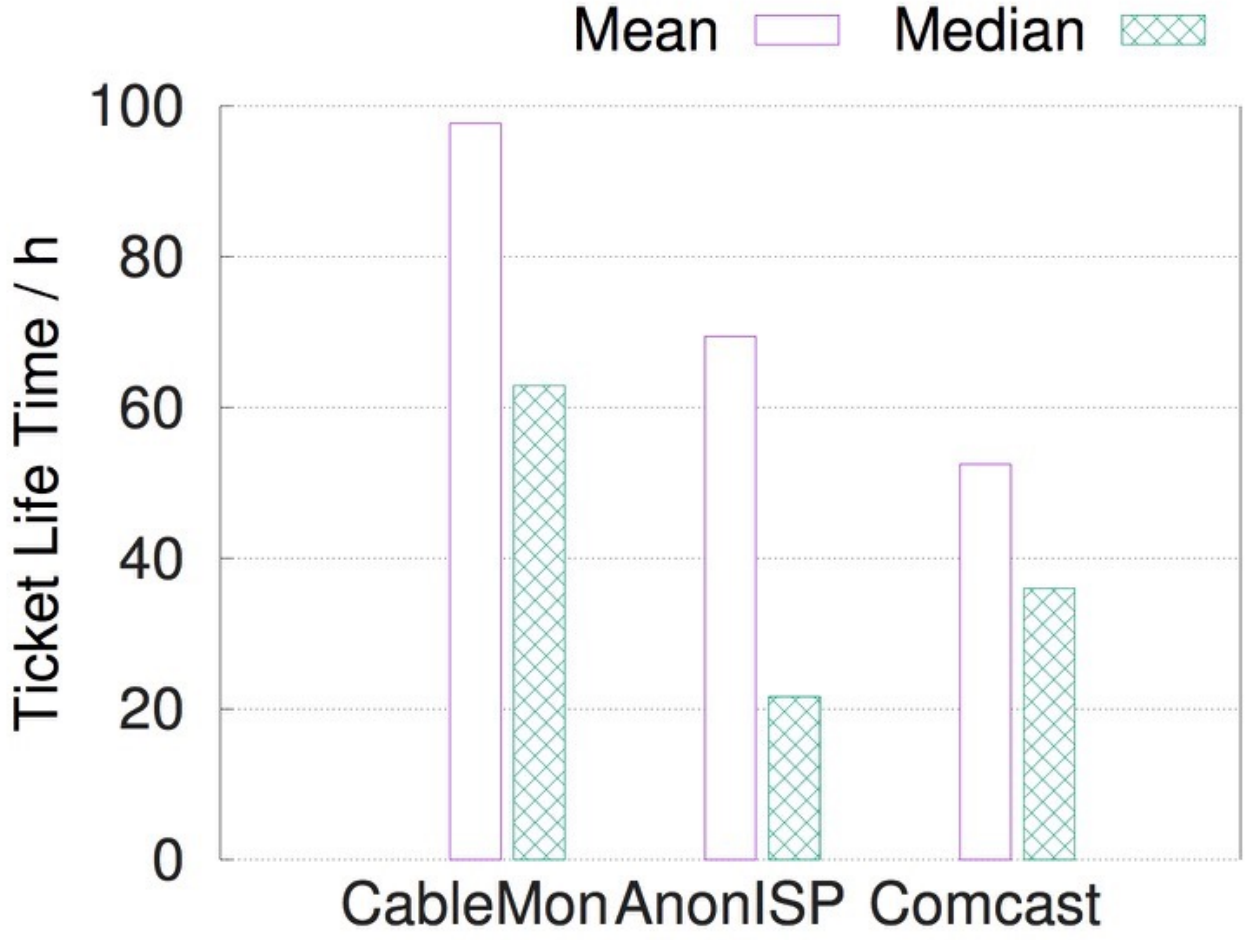
# Ticket Life Time

- Tickets detected by CableMon
  - last for longer time
  - indicate harder issues



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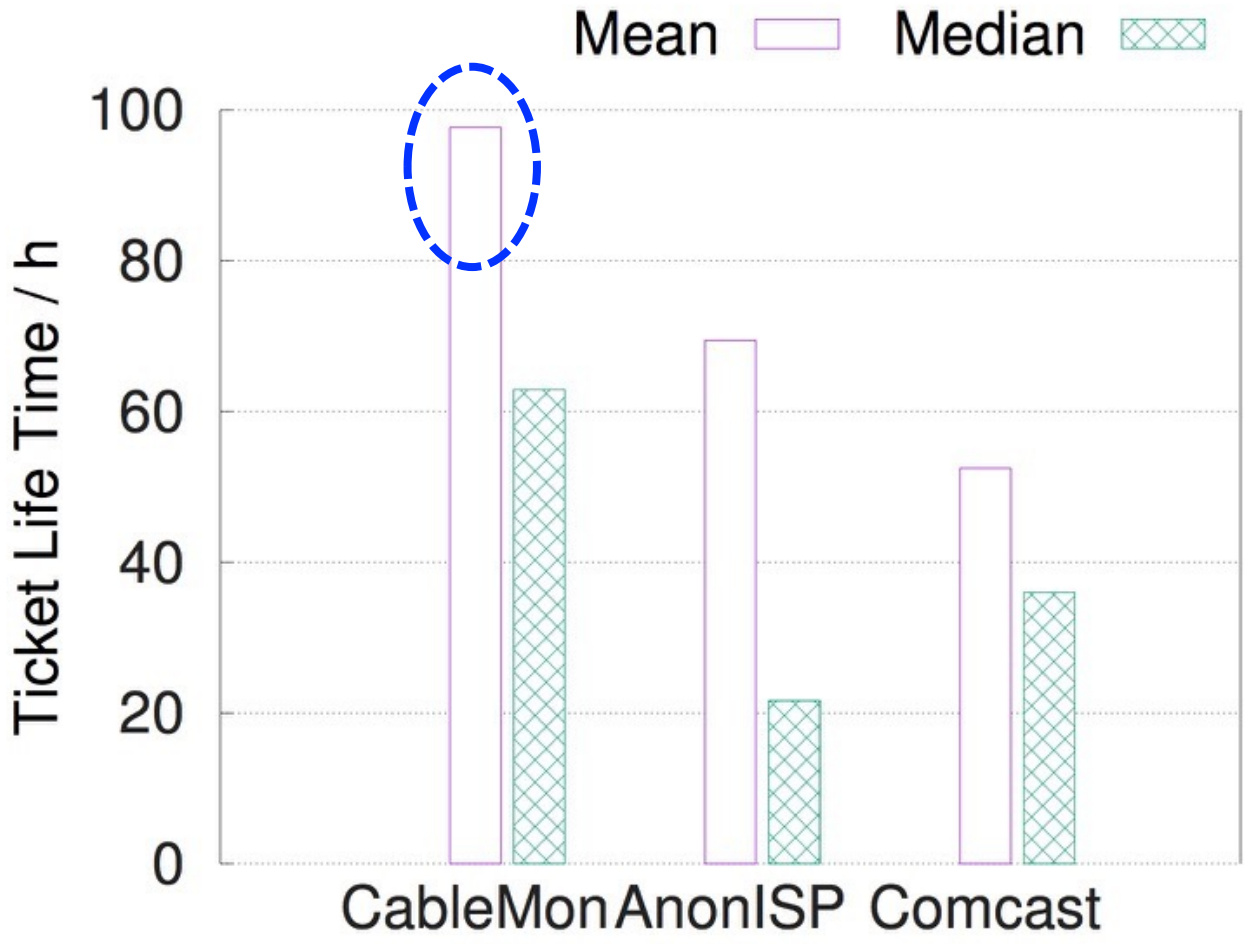

# Type of Tickets

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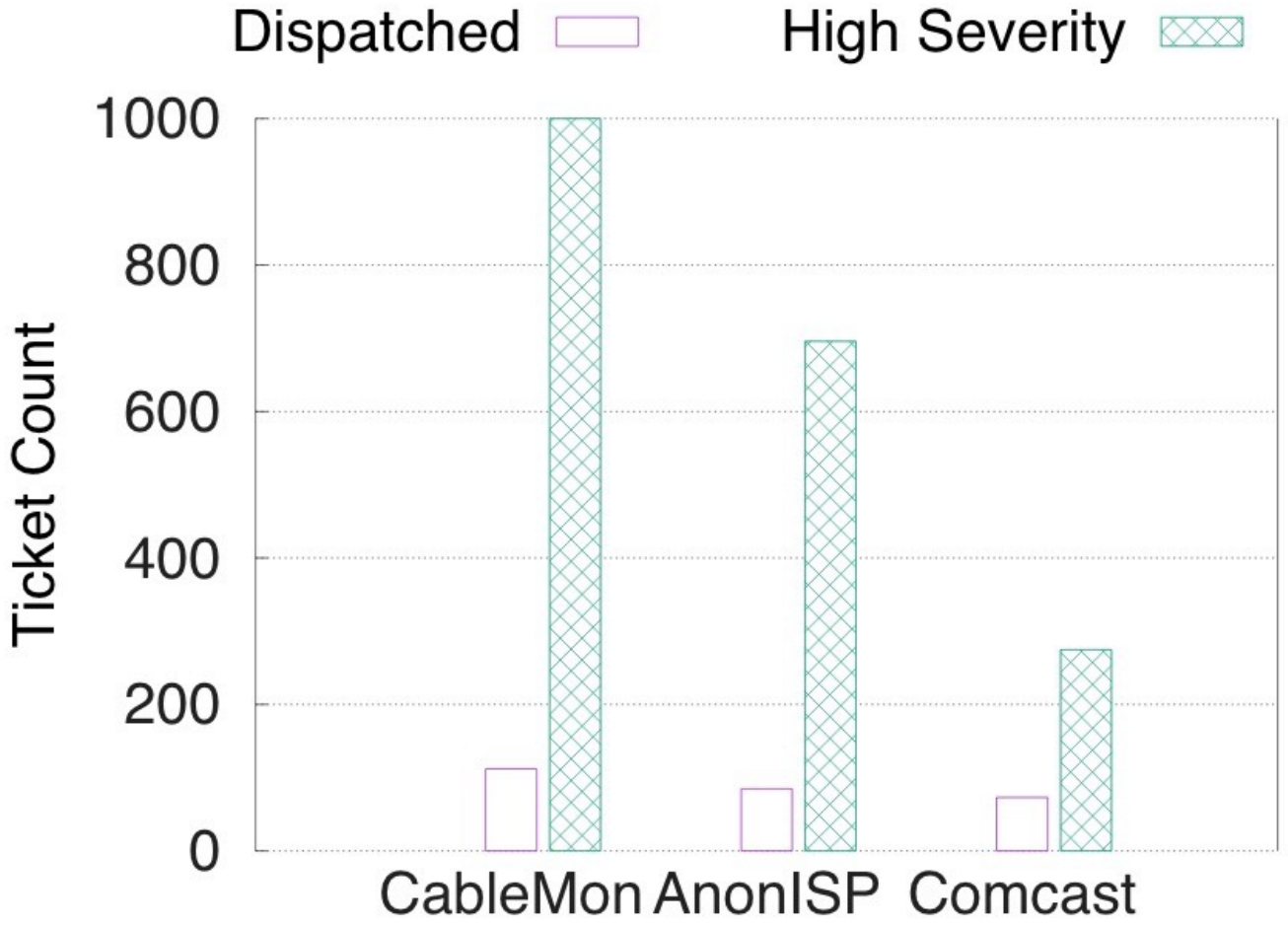

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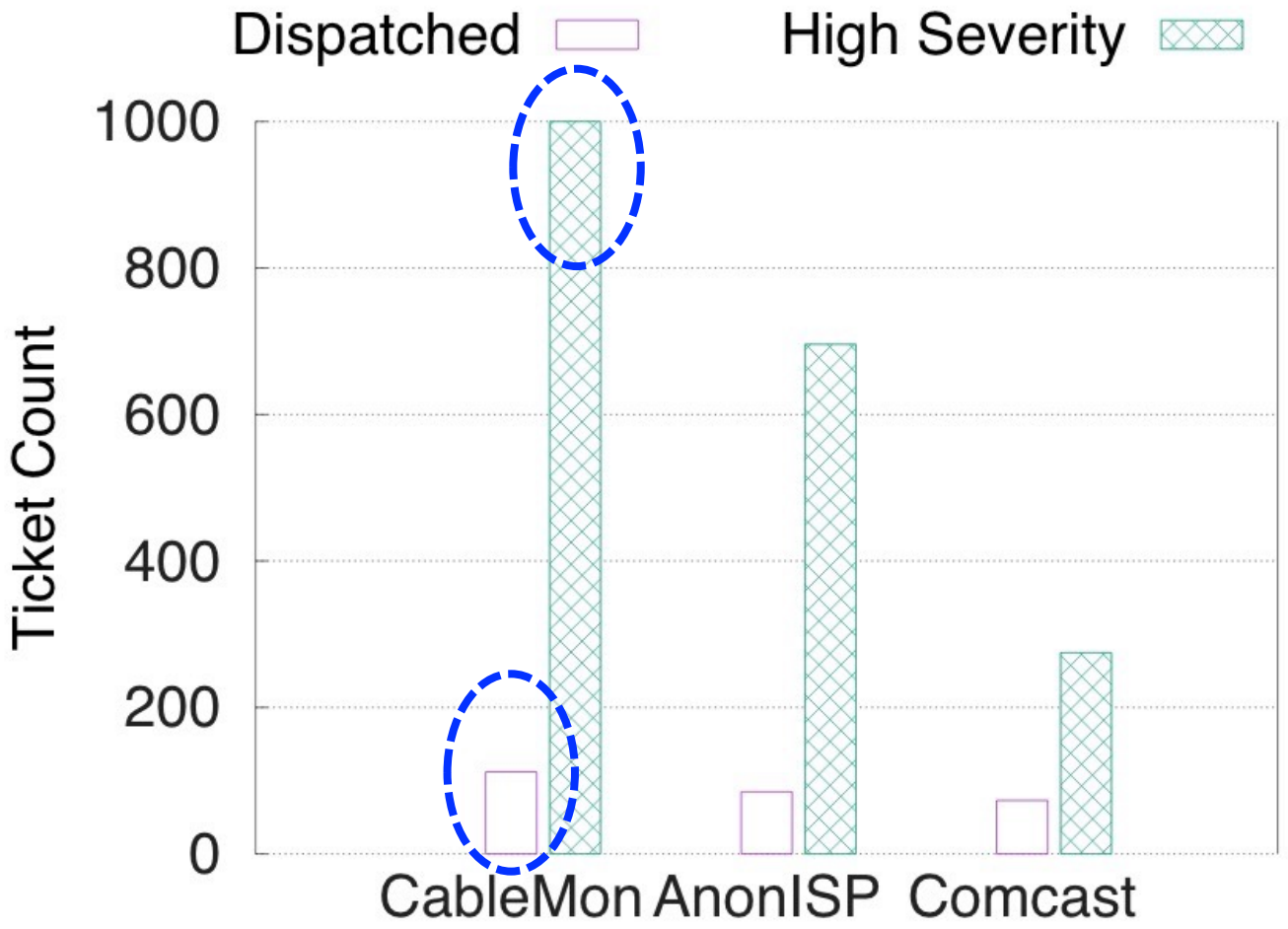

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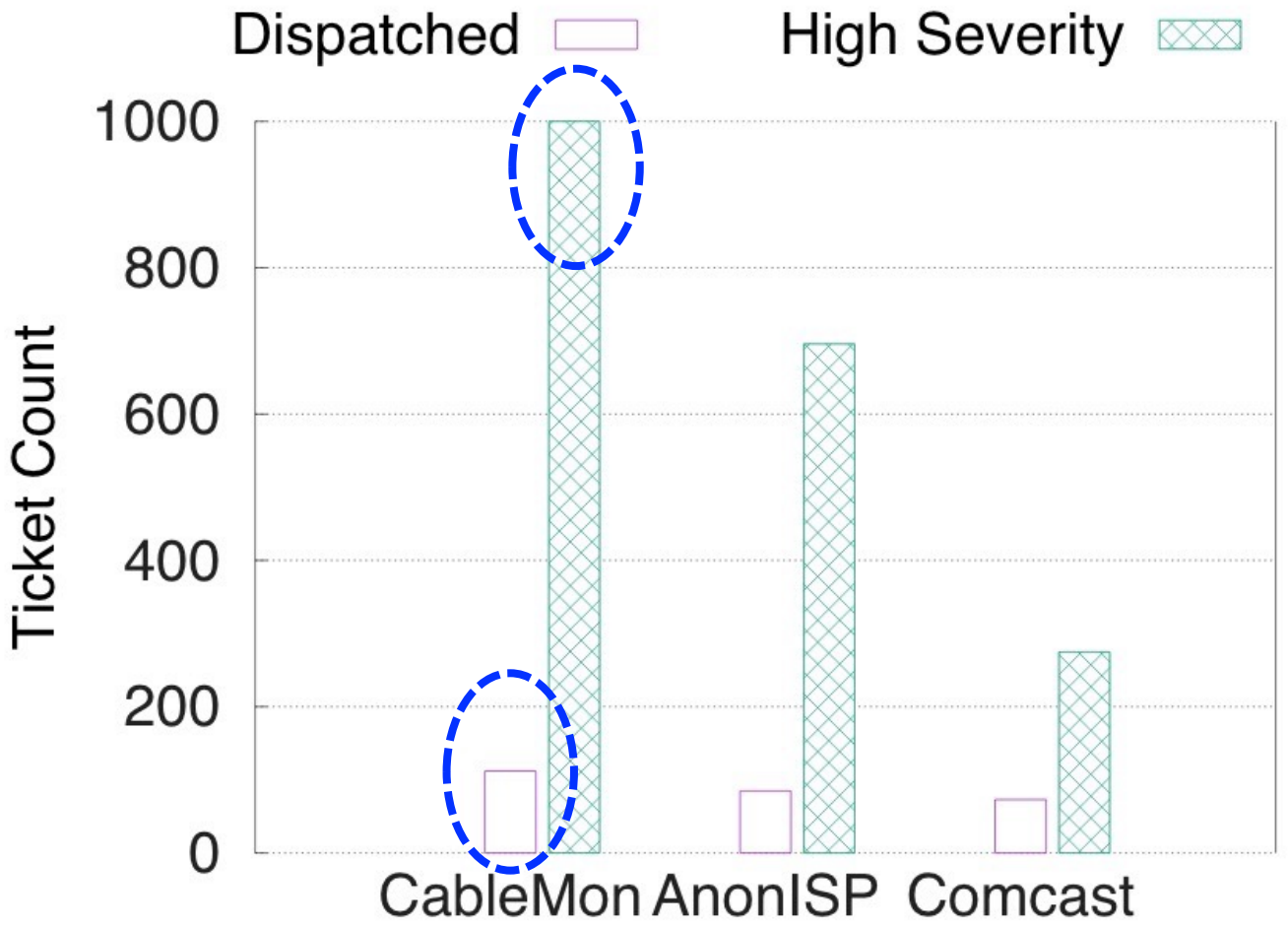


**More results can be found in the paper**

# Conclusion

- CableMon to detect network faults
- Use tickets as hints: No manual labeling
- Overcome the noise from both PNM data and customer trouble tickets
- Achieve high ticket prediction accuracy, and moderate ticket coverage

# Thanks for your attention!

# Questions?