Denial of Service and Anomaly *Detection*

Vasilios A. Siris

Institute of Computer Science (ICS)

FORTH, Crete, Greece

vsiris@ics.forth.gr

SCAMPI BoF, Zagreb, May 21 2002

Overview

- What the problem is and why it is difficult
- Where and why naïve schemes fail
- Consider two algorithms
  - Adaptive Threshold
  - CUSUM (CUmulative SUM)
- Application to SYN attack detection
- Experimental results
- Conclusions and future work

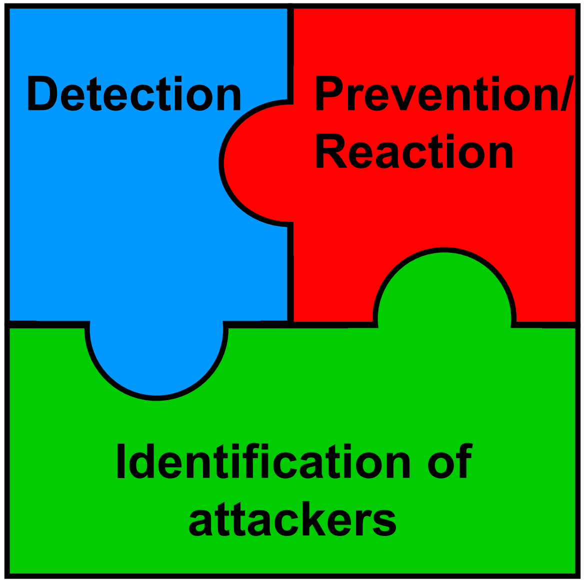
Denial of Service (DoS) attacks

- Aim is to prevent users from receiving service, with some minimum performance
- Achieved by consuming resources
  - Bandwidth
  - Memory
  - Router forwarding capacity
  - Other services: DNS
- Technique: flooding

Importance of DoS attacks

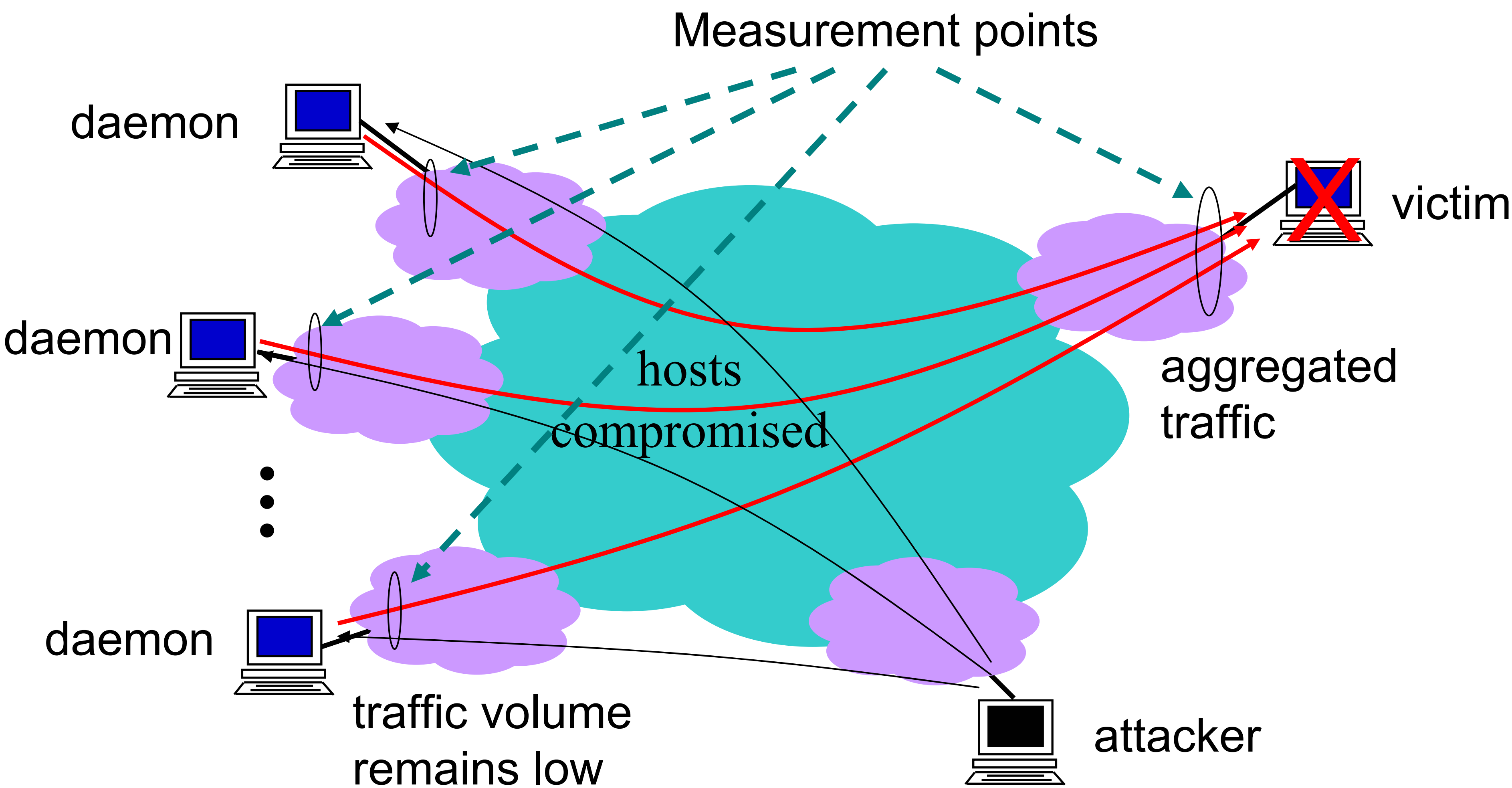
- Recent surveys:
  - 40% of all attacks are DoS (2002 CSI/FBI)
  - 90% of all DoS attacks are TCP attacks (2001 Moore et al)
- Cost of attack = many € or $
  - Several millions to billions $ estimated loss from Feb 2000 attack at Yahoo, CNN, Amazon, etc
- Attacks are increasing
  - DNS route server attack in Oct. 2002
  - DOLnet's attack in Dec. 2002
  - 55% Web attacks are DoS (2002 CSI/FBI)

The DoS problem



- Our focus on detection of DoS attacks
  - Early and reliable detection of attacks
  - Detection of low intensity attacks

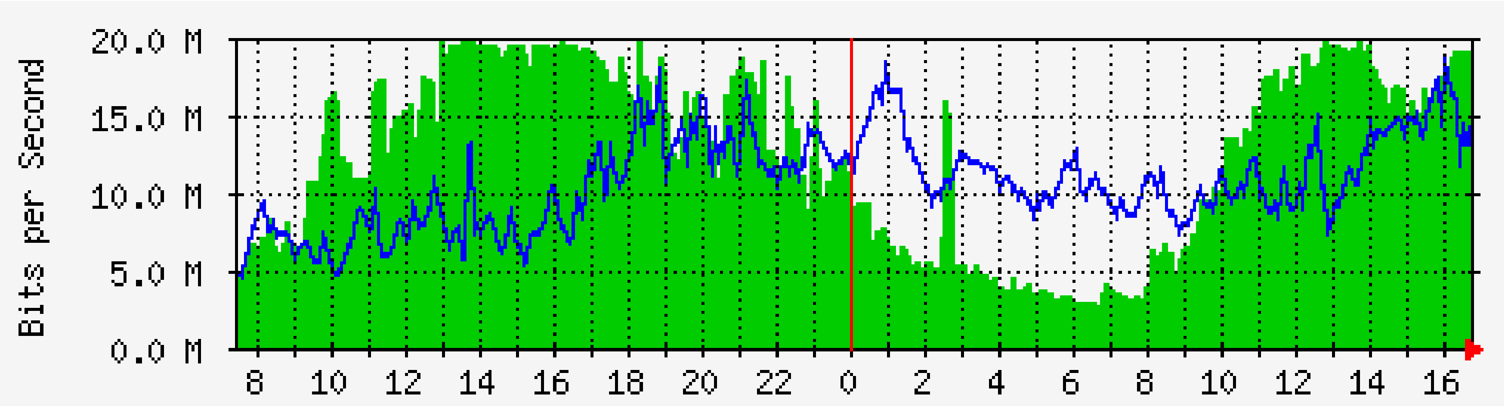
Distributed DoS attack



Approaches to anomaly detection

- Alarm when behavior deviates from normal
- Specify normal behavior (operational model)
  - Thresholds: e.g. load < 0.7
- Learn normal behavior
  - Mean and standard deviation statistics
  - Time series analysis: advantage is that they take into account time correlations
    - Change point detection (hypothesis testing)
  - Other approaches: bayesian statistics, neural nets
- DoS attacks one example of anomaly
  - Link/device failures

Non-adaptive approaches not robust

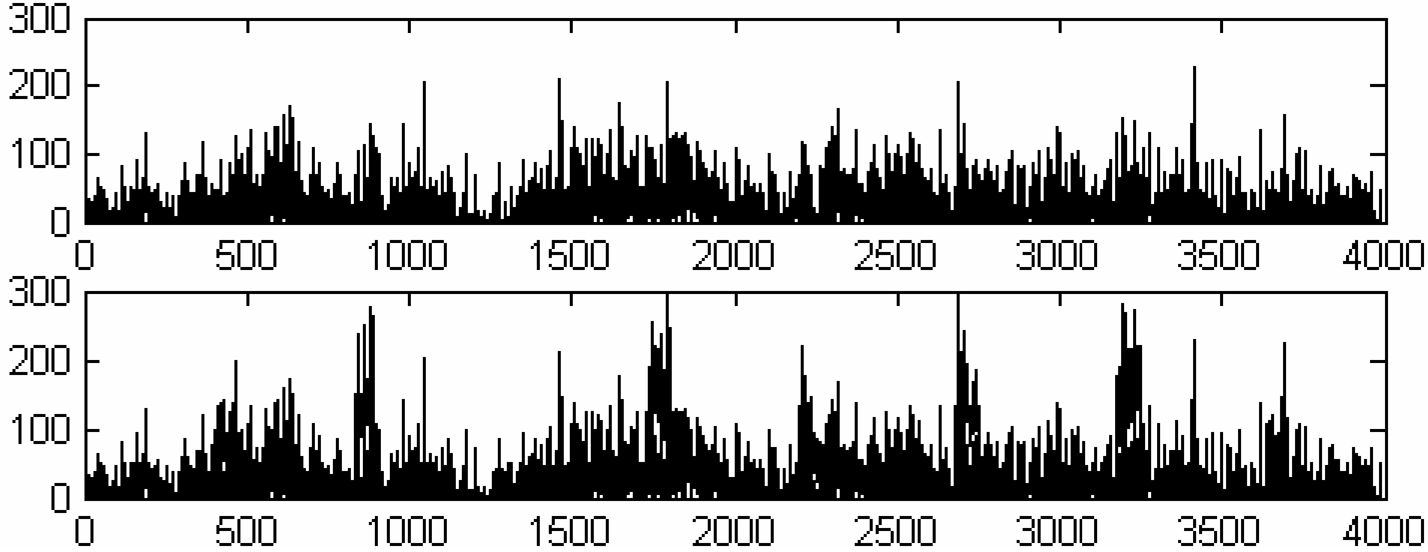


- Fixed threshold tests (e.g. normal < 0.7) will fail due to normal/regular traffic variations
- Why not consider an adaptive threshold ?

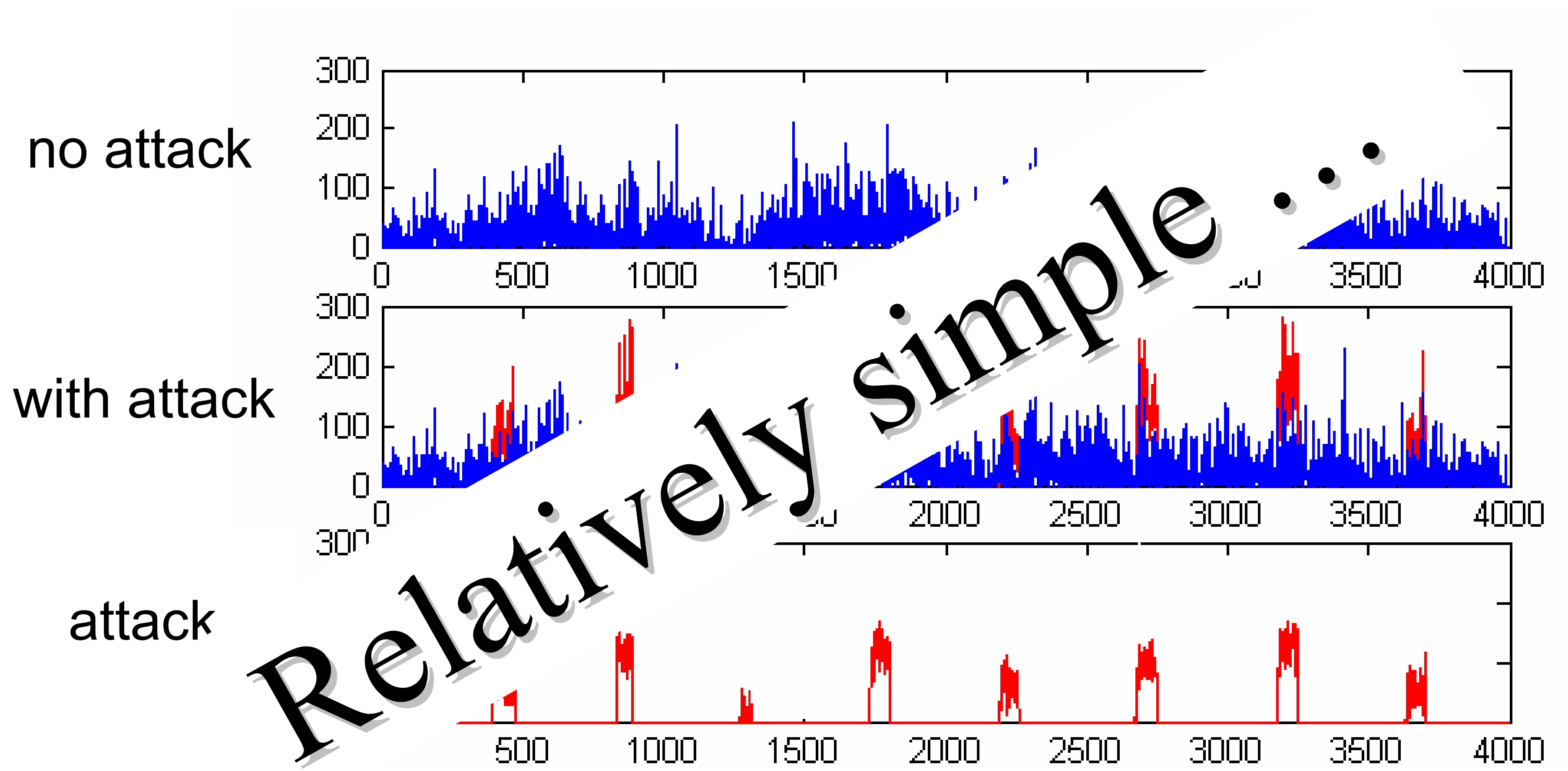
Detection of some attacks simpler

no attack

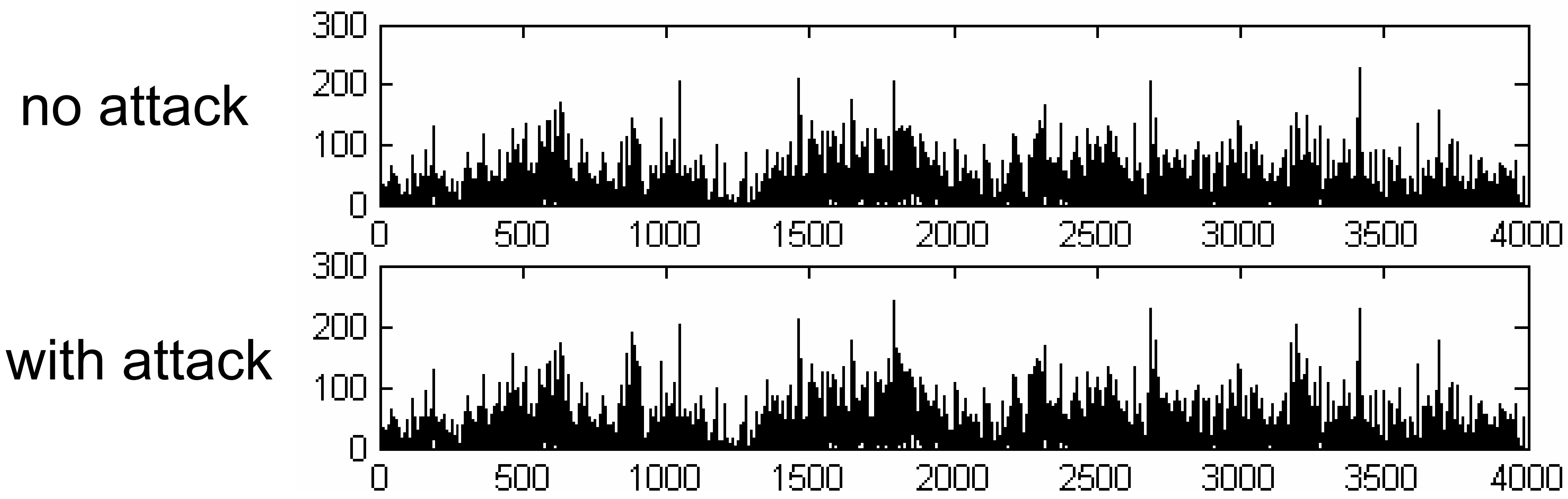
with attack



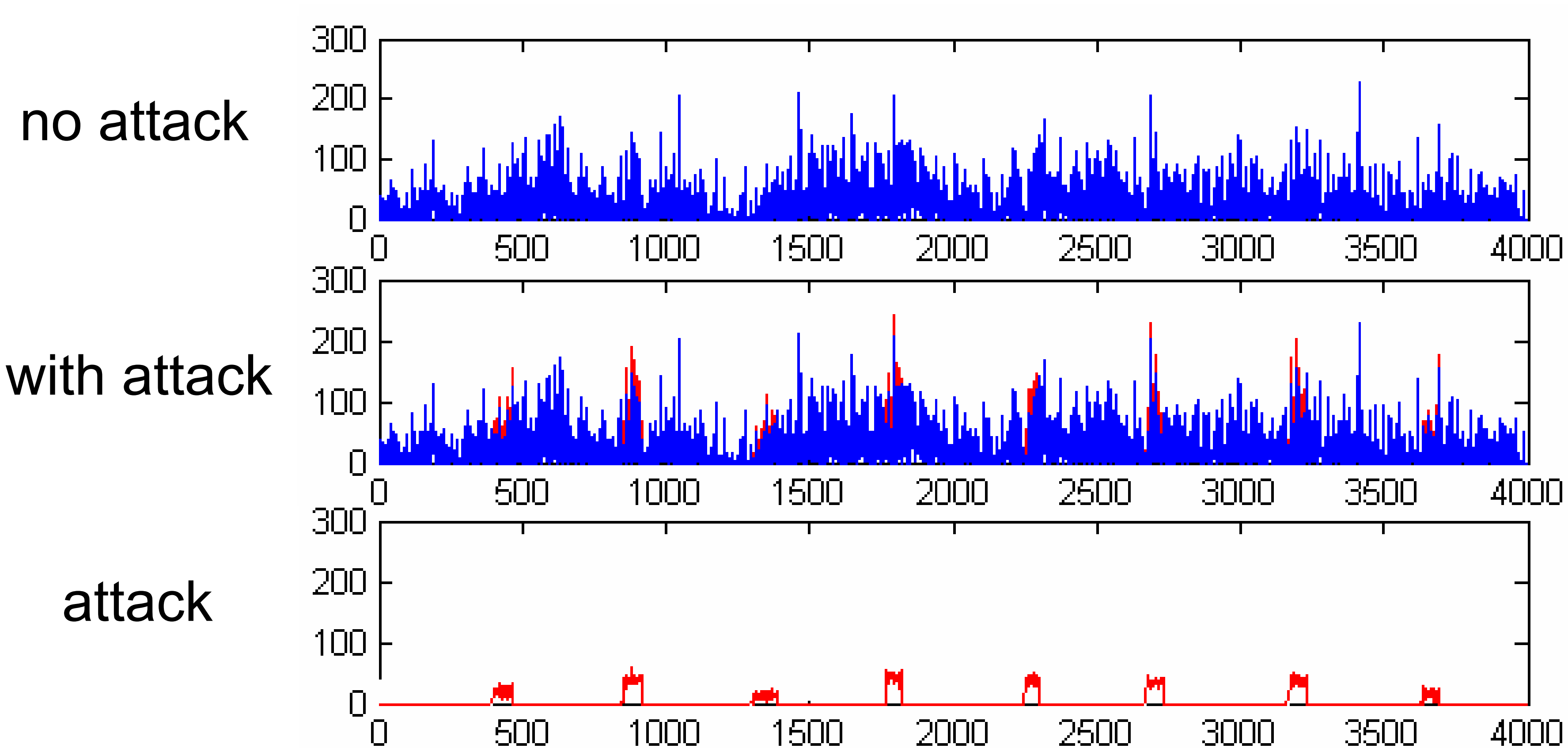
Detection of some attacks simpler



Some attacks are more subtle



Some attacks are more subtle



What and when to measure

- Variable measured:
  - Aggregate traffic volume (in fixed time intervals)
  - Traffic volume per flow (in fixed time intervals)
  - # of requests, e.g. TCP, http, …
  - Inter-arrival time of requests
  - Duration of requests (average or bin)
  - Pkt size (average or bin)
- Statistic: Mean, variance, covariance, hurst
- When to measure: order of minutes
  - 10 minutes in our experiments

Algorithms investigated

- Adaptive threshold
  - Adaptively measure mean rate
  - Alarm when rate more than some percentage (e.g. > 150% of mean)
- CUSUM (CUmulative SUM)
  - Adaptively measure mean rate
  - Sum the volume sent above some average factor
  - Alarm when volume more than some threshold

Adaptive Threshold (AT)

- Let y_t be time series of measurements
  - E.g. # of SYN packets in an interval T
- Mean μ_t measured over some past window L
  - By adaptively measuring mean can adjust to periodic (non-stationary) changes

Adaptive Threshold (AT)

- Let y_t be time series of measurements
  - E.g. # of SYN packets in an interval T
- Mean μ_t measured over some past window L
  - By adaptively measuring mean can adjust to periodic (non-stationary) changes
- Alarm condition

$$\text{If} \quad y_t > \beta\mu_t \quad \text{Alarm at } t$$

- Parameters:
  - T (measurement interval), L (averaging interval), β>1 (threshold)

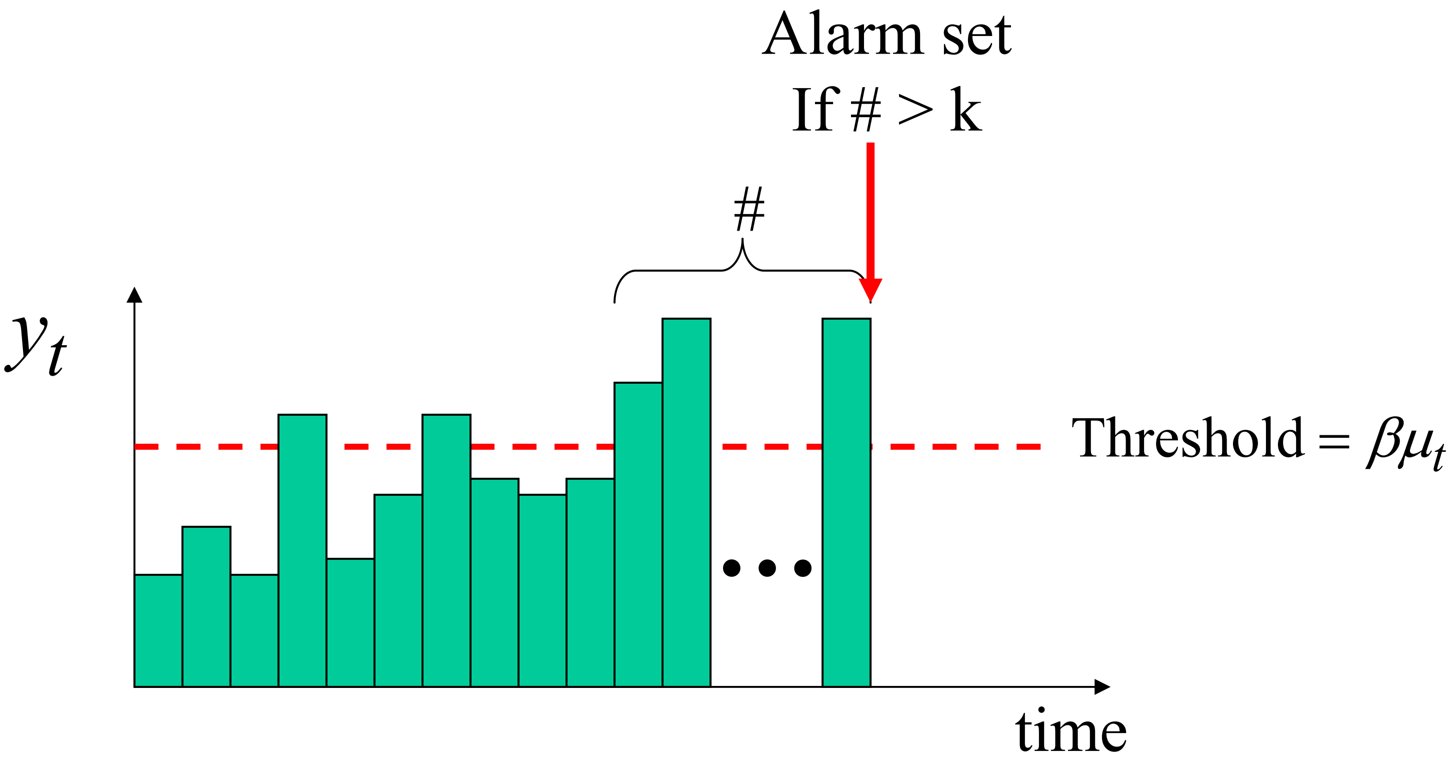
Adaptive Threshold k (AT-k)

- More robust if alarm set when threshold exceeded for # k of consecutive intervals
- Alarm condition

$$\text{If} \quad \sum_{i=t-k}^{t} 1_{\{y_i > \beta\mu_i\}} > k \quad \text{then} \quad \text{ALARM at } t$$

- Parameters:
  - T (measurement interval), L (averaging interval), β (threshold), k (# of intervals threshold exceeded)

Adaptive Threshold: intuition



- Assuming fixed mean μ_t

CUSUM algorithm

- Based on hypothesis testing
- Current hypothesis (no attack): θ_0
- Alternative hypothesis θ_1 : $\mu_1 = \beta\mu_0$ $\sigma_1 = \sigma_0$

$$s_i = \ln \frac{p_{\theta_1}(y_i)}{p_{\theta_0}(y_i)}$$

CUSUM algorithm

- Based on hypothesis testing
- Current hypothesis (no attack): θ_0
- Alternative hypothesis θ_1 : $\mu_1 = \beta\mu_0 \quad \sigma_1 = \sigma_0$

$$s_i = \ln \frac{p_{\theta_1}(y_i)}{p_{\theta_0}(y_i)}$$

$$S_t = \sum_{i=0}^{t} s_i \qquad S_{\min} = \min_{0<k\leq t} S_k$$

- Alarm condition

$$\text{If} \quad S_t - S_{\min} > h \quad \text{then} \quad \text{ALARM at } t$$

- Parameters: β (surplus), h (alarm threshold)

CUSUM algorithm: another view

- Mean μ estimated using EWMA
- Surplus: $\mu_1 = \mu_1' + \mu = \beta\mu$ (e.g. $\mu_1 = 1.5 \times \mu$)

$$g_t = \left[g_{t-1} + \frac{\mu_1'}{\sigma^2}\left(y_t - \frac{\mu + \mu_1}{2} \right) \right]^+$$

CUSUM algorithm: another view

- Mean μ estimated using EWMA
- Surplus: $\mu_1 = \mu_1' + \mu = \beta\mu$ (e.g. $\mu_1 = 1.5 \times \mu$)

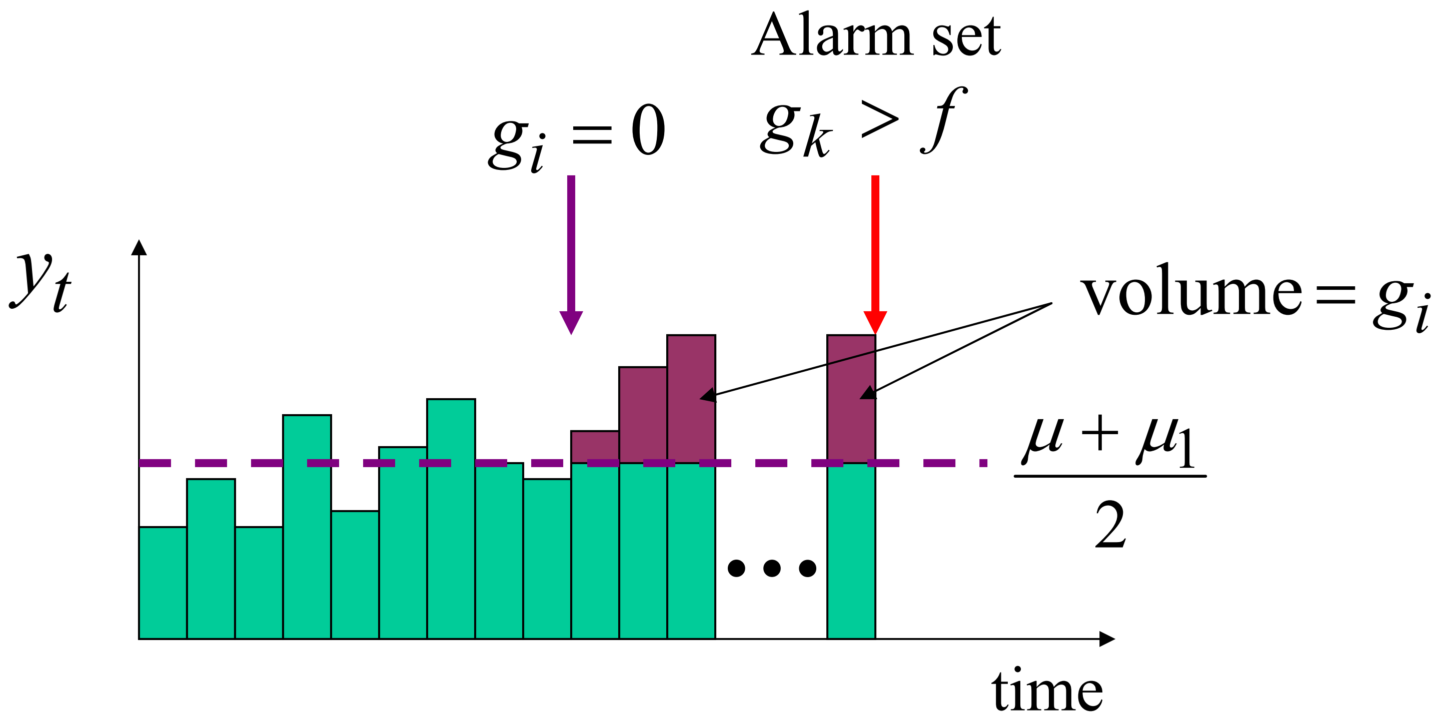
$$g_t = \left[g_{t-1} + \frac{\mu_1'}{\sigma^2} \left(y_t - \frac{\mu + \mu_1}{2} \right) \right]^+$$

- Alarm condition

$$\text{If} \quad g_t > h \quad \text{then} \quad \text{ALARM at } t$$

- Parameters:
  - $\beta > 1$ (surplus), h (alarm threshold)

CUSUM algorithm: intuition

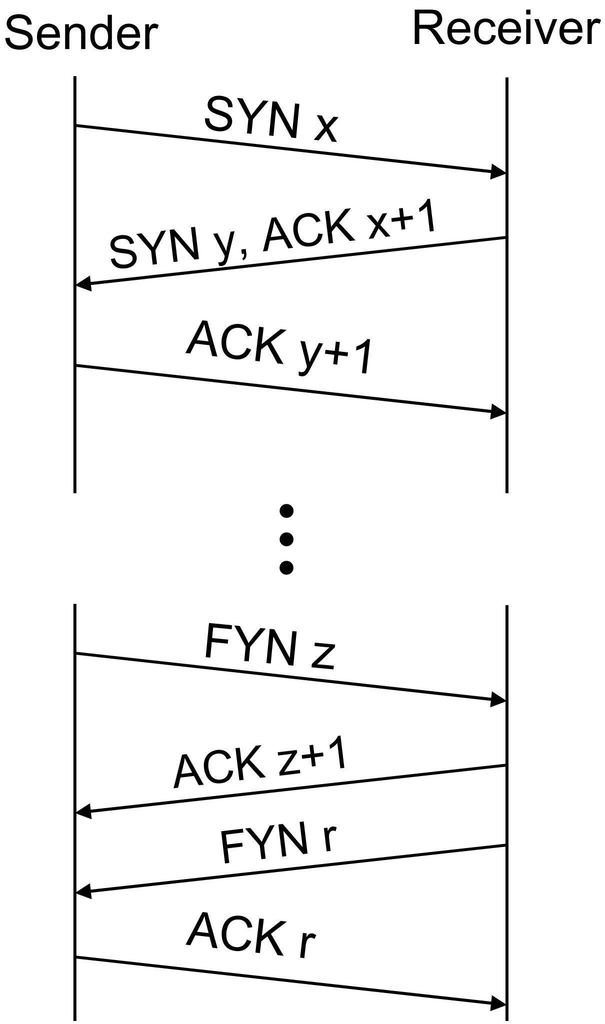


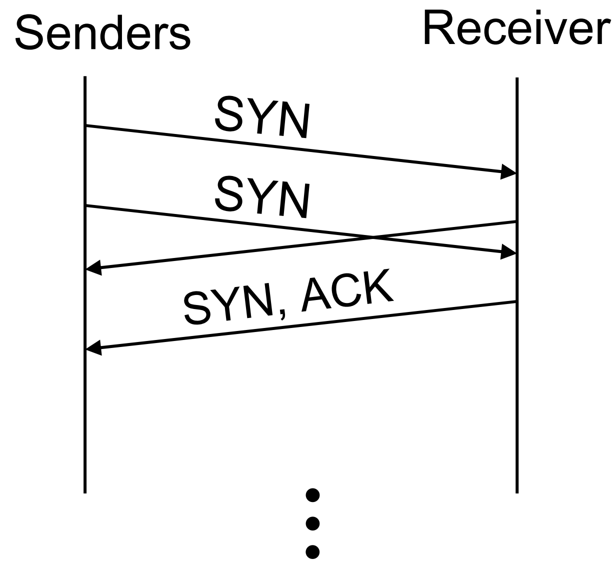
- Assuming $\frac{\mu + \mu_1}{2}$ constant
- Accumulates excess traffic (memory)

Types of DoS attacks

- TCP SYN flooding
- ICMP flooding
- UDP flooding
- SMURF attack

Application to SYN attack detection





- Exploits TCP's three way handshake
- Half-open connections consume resources
- Source IP addresses spoofed

Performance measures

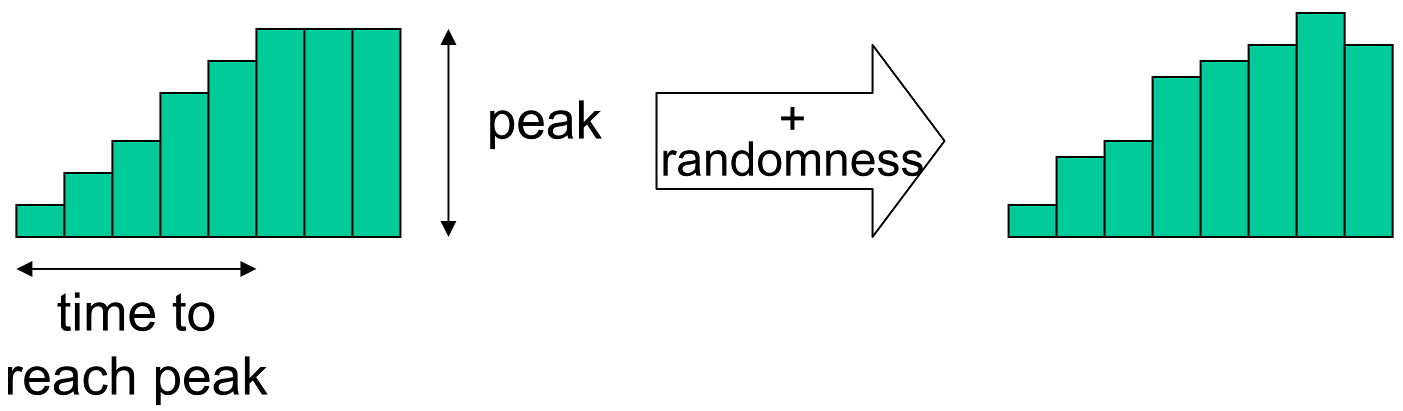
- Attack detection ratio
- False alarm ratio (false positives)
- Detection delay
- Robustness
- How tunable the algorithm is
  - Tradeoff between detection ratio, false alarm ratio and detection delay
- Evaluate above for different attack types
  - Intensity of attack (amplitude)
  - How fast it reaches peak amplitude

Experiments

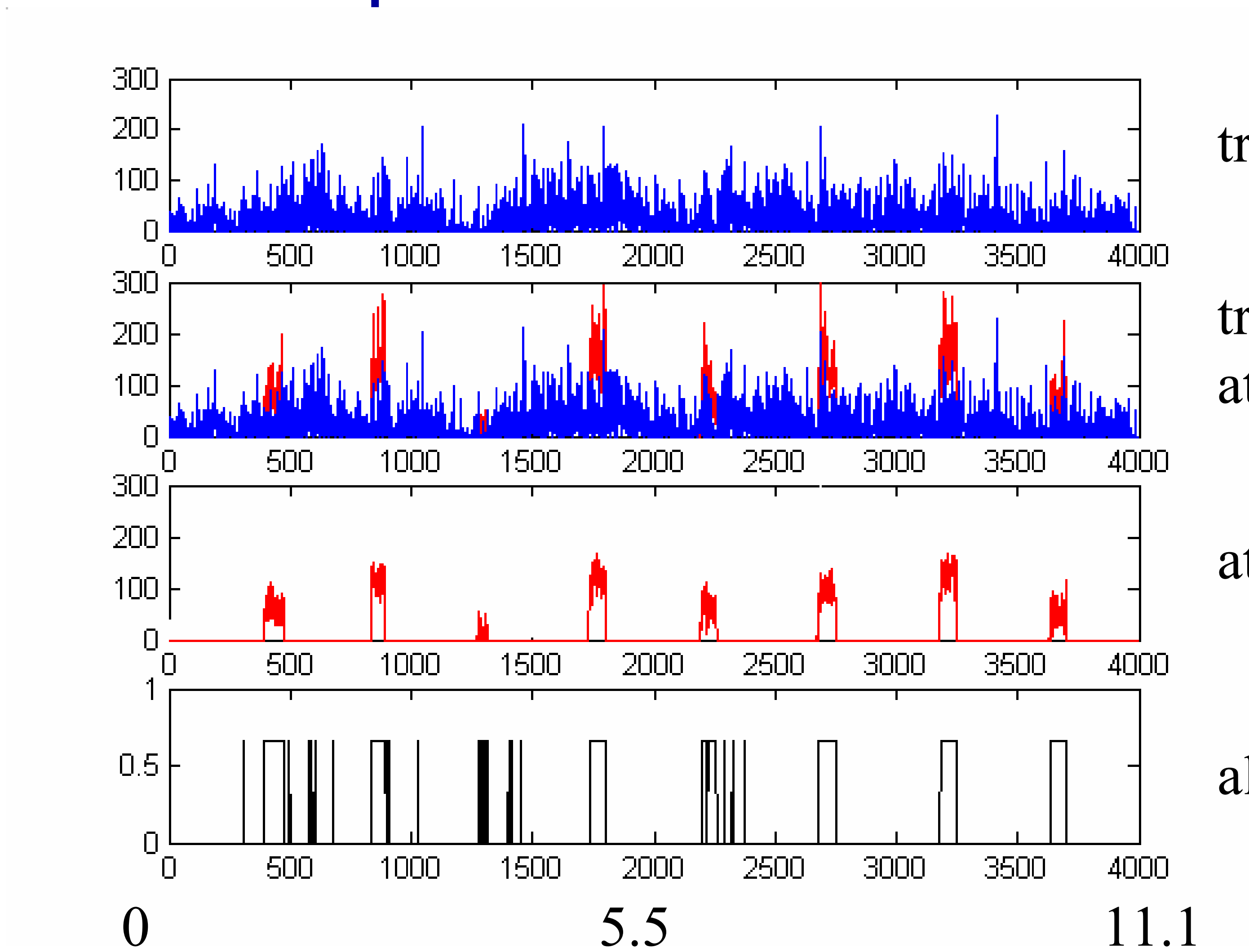
- Considered actual trace with no attacks ~ 20 hours
  - # of SYN pkts in 10 second intervals

Experiments

- Considered real trace without attacks ~ 20 hours
  - # of SYN pkts in 10 second intervals
- 50 runs, 95% confidence interval
- Synthetic attacks
  - Intensity of attack (peak)
  - Time to reach peak
  - Inter-arrival: exponential, 400 sec

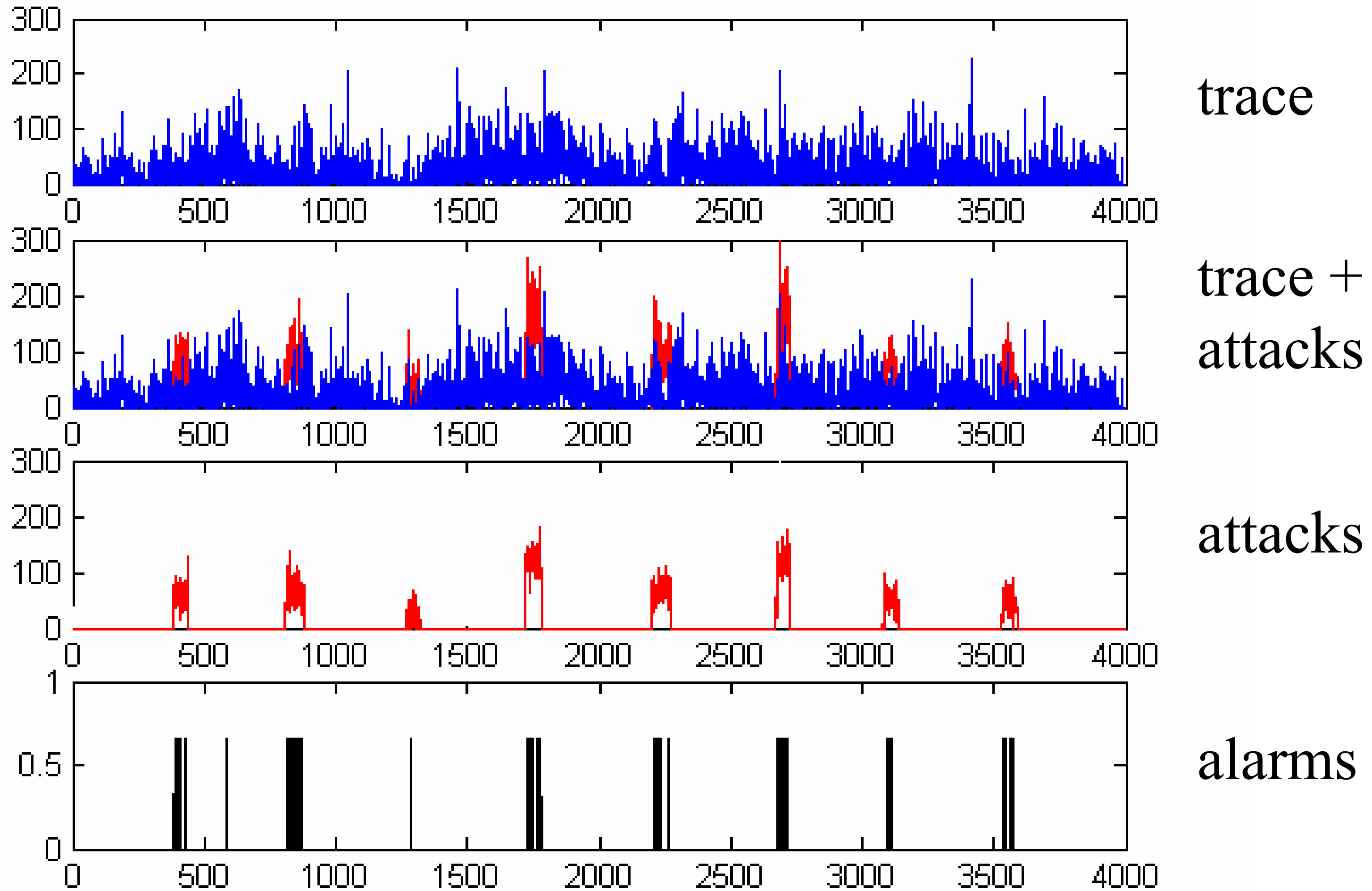


Adaptive Threshold – k



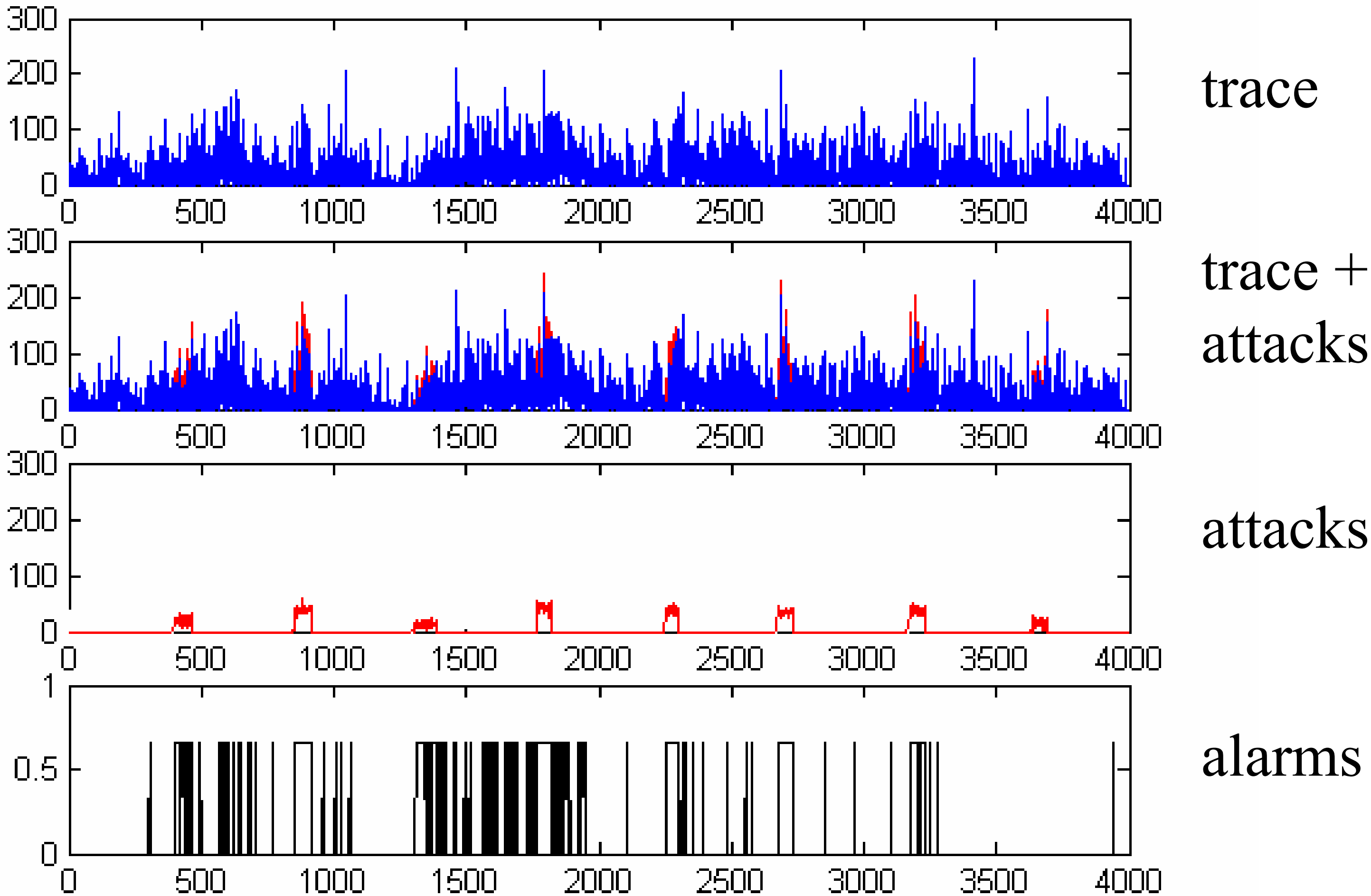
- Intense attack: rate ~ 250% mean

CUSUM



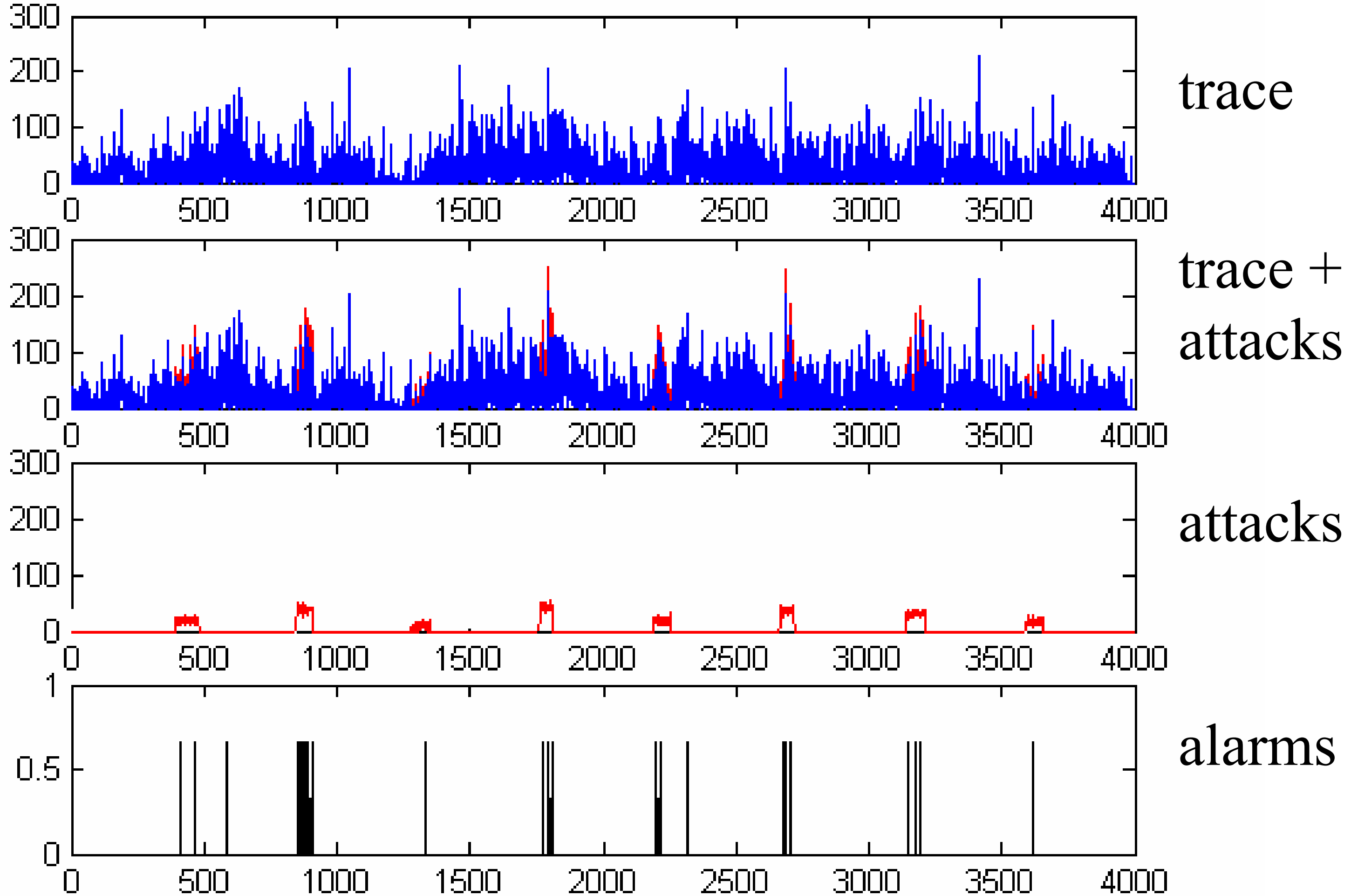
- Intense attack: rate ~ 250% mean

Adaptive Threshold – k



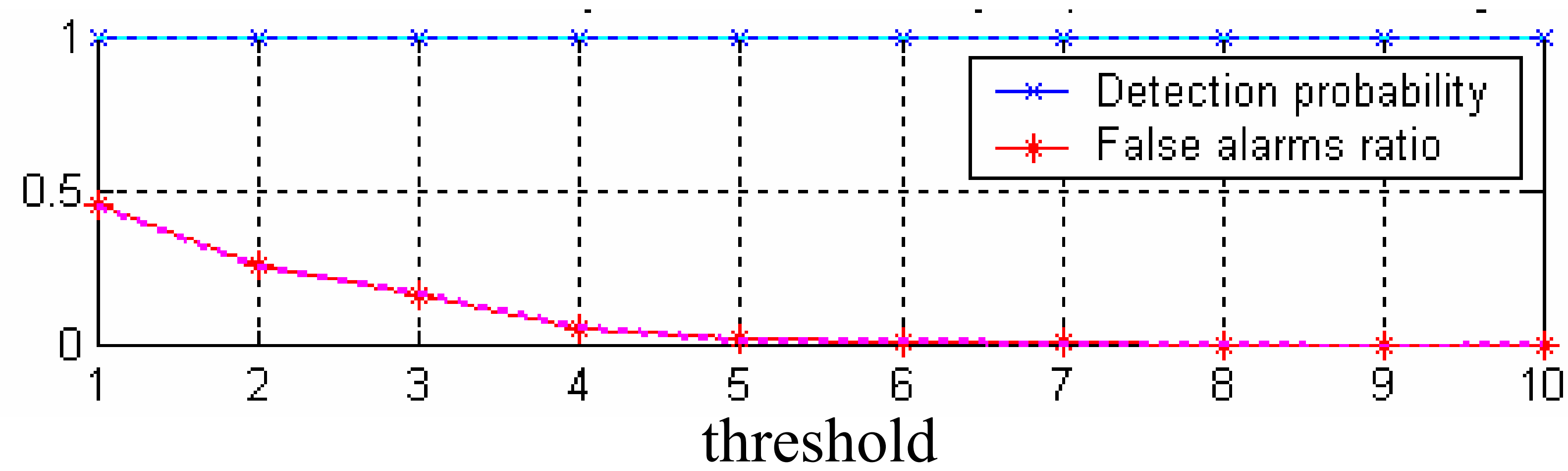
- small attack: rate ~ 10% mean

CUSUM



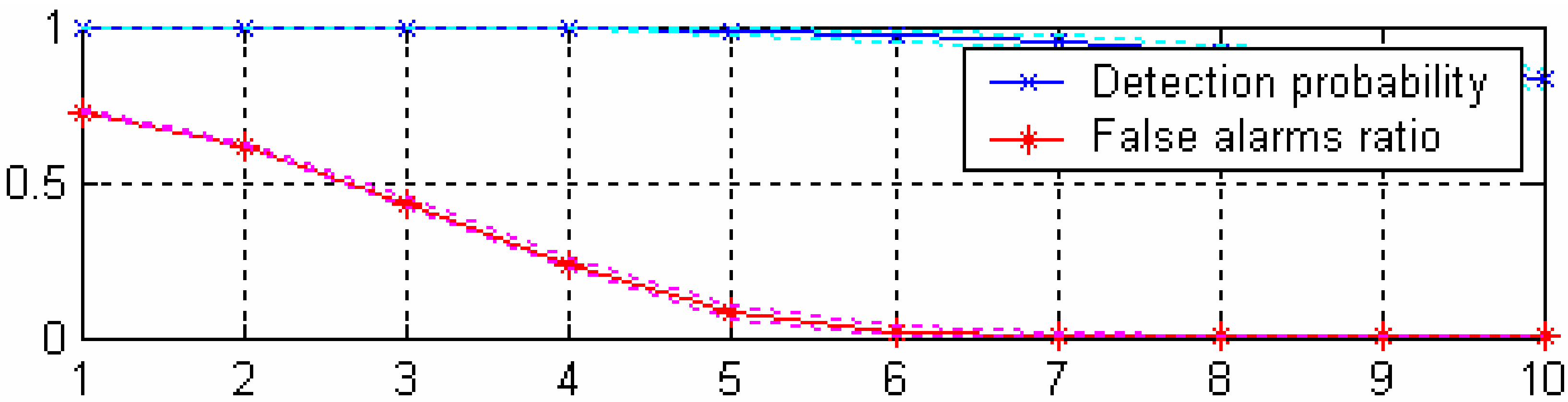
- small attack: rate ~ 10% mean

CUSUM



- Attack amplitude: 150% mean
- Time to reach peak: 90 sec

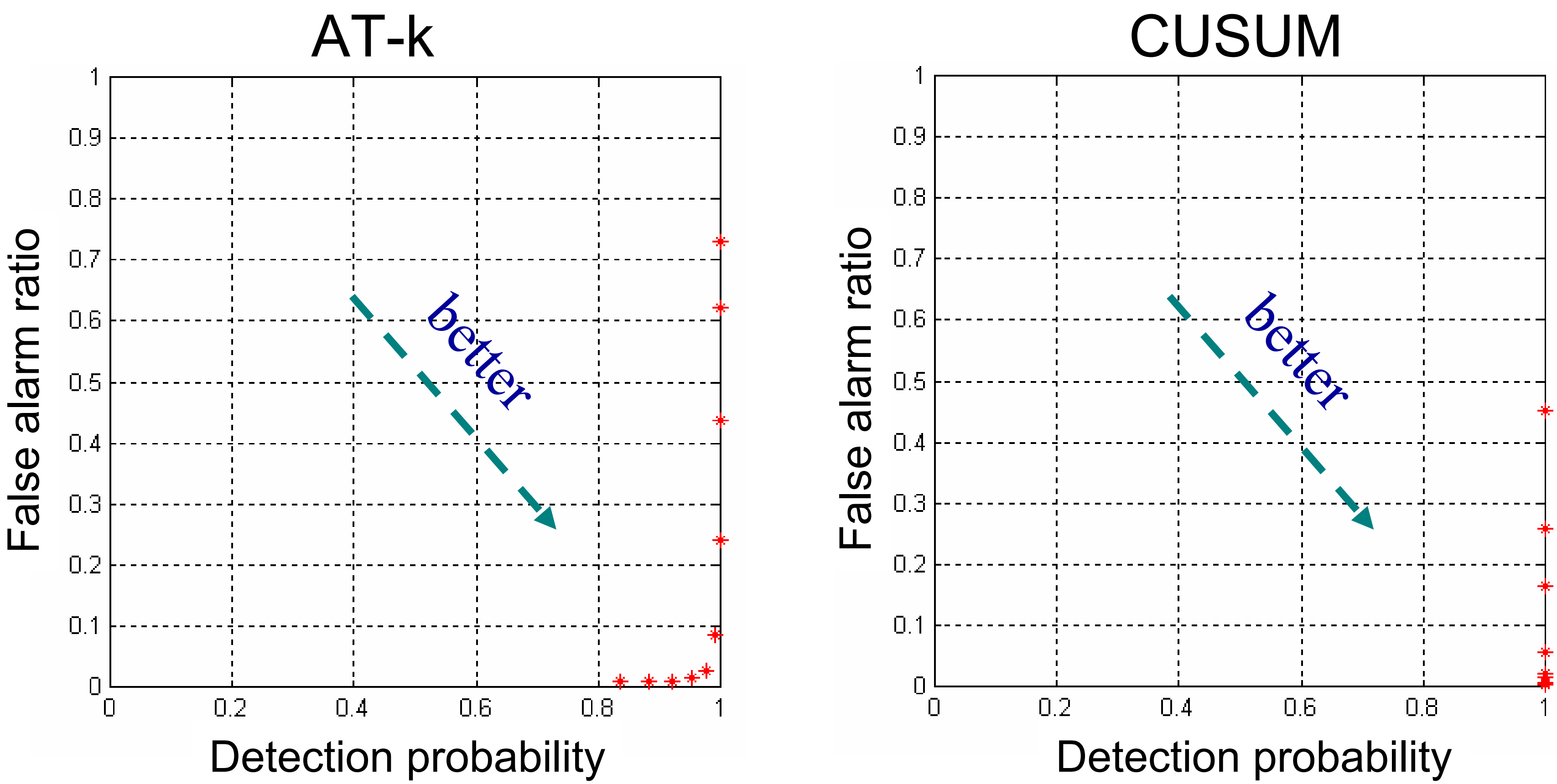
Adaptive Threshold - k



k (consecutive intervals of excess load)

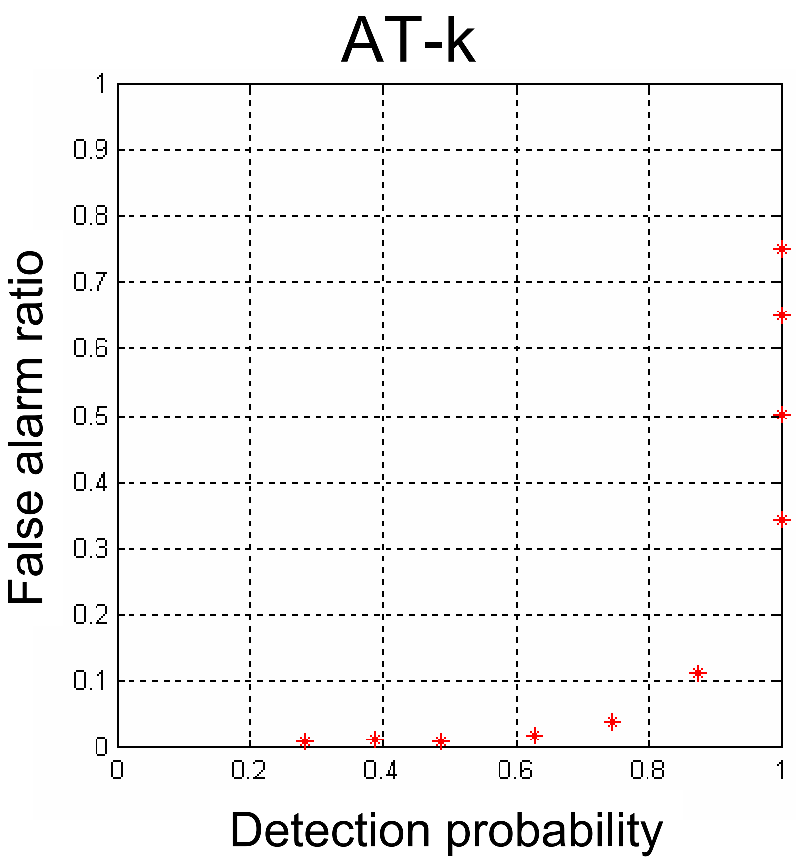
- Attack amplitude: 150% mean
- Time to reach peak: 90 sec

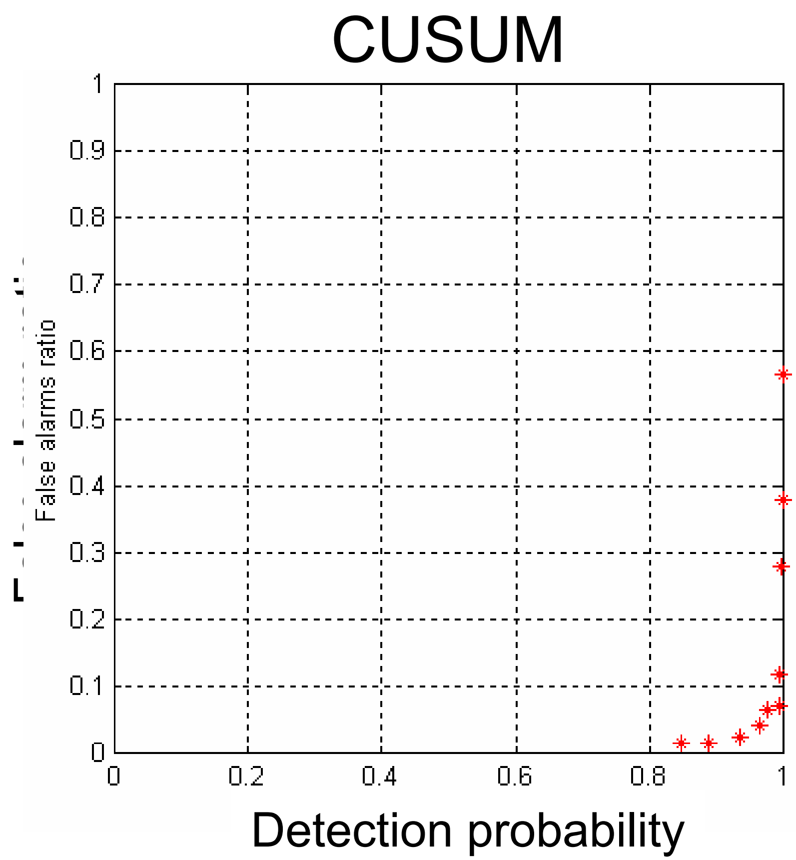
AT-k versus CUSUM



- Attack amplitude: 150% mean
- Time to reach peak: 90 sec

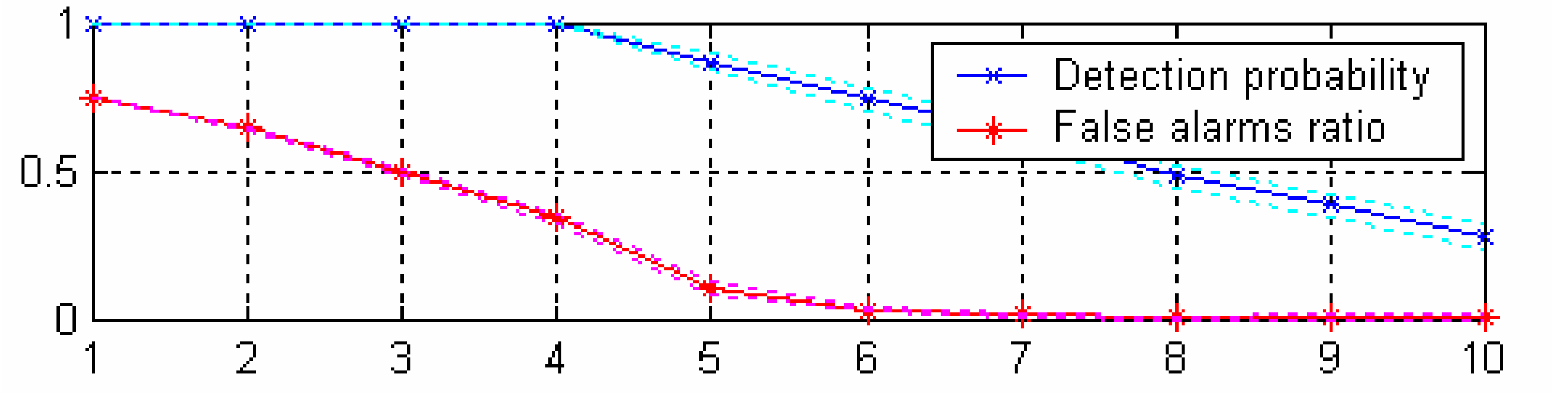
AT-k versus CUSUM





- Attack amplitude: 50% mean
- Time to reach peak: 90 sec

Adaptive Threshold - k



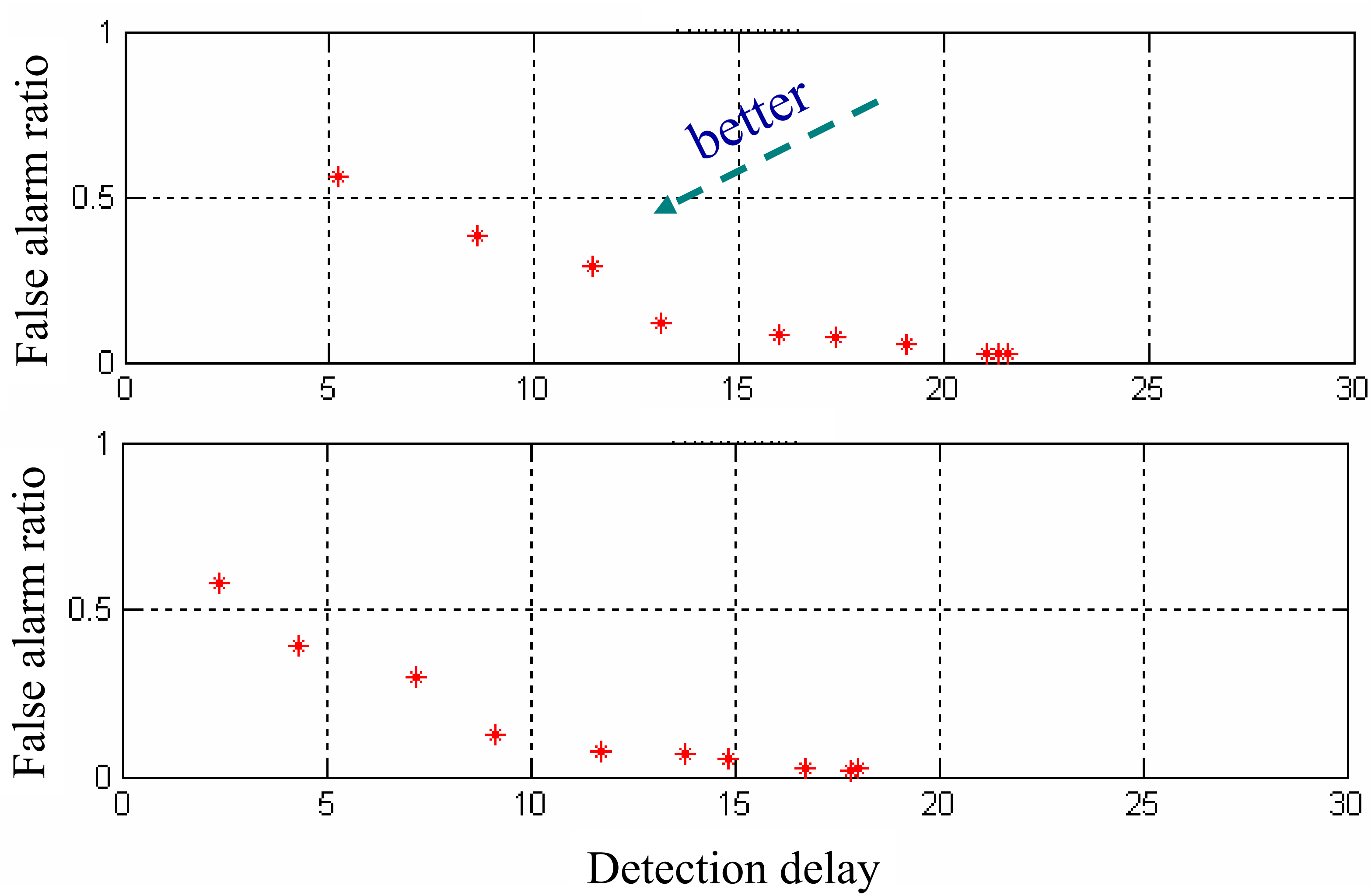
k (consecutive intervals of excess load)

- Attack amplitude: 50% mean
- Time to reach peak: 90 sec

CUSUM

Attack peak at 90 sec

Attack peak at 10 sec



- Attack amplitude: 50% mean

Experiment results

- Performance depends on attack characteristics
- For some (intense) attack types straightforward procedures can be effective
- But simple procedures are not robust for different attacks
- Sound statistical methods are robust and not necessarily complex
- Intuition on how to tune parameters important

Future work

- Application to other measures & statistics
- Combination of alarms
- Application to QoS measurements
  - Measurements: delay, jitter, throughput
  - Up to now: alert when measurements exceed guarantees
  - Idea: apply anomaly detection to measurements => early detection of QoS violations

Denial of Service and Anomaly *Detection*

Vasilios A. Siris
Institute of Computer Science (ICS)
FORTH, Crete, Greece
vsiris@ics.forth.gr

SCAMPI BOF, Zagreb, May 21 2002