Attacker Traceback and Countermeasure with Cross-layer Monitoring in Wireless Multi-hop Networks

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Introduction

- Wireless multi-hop networks are especially vulnerable to DoS/DDoS attack due to its limited resource (bandwidth, host resources)

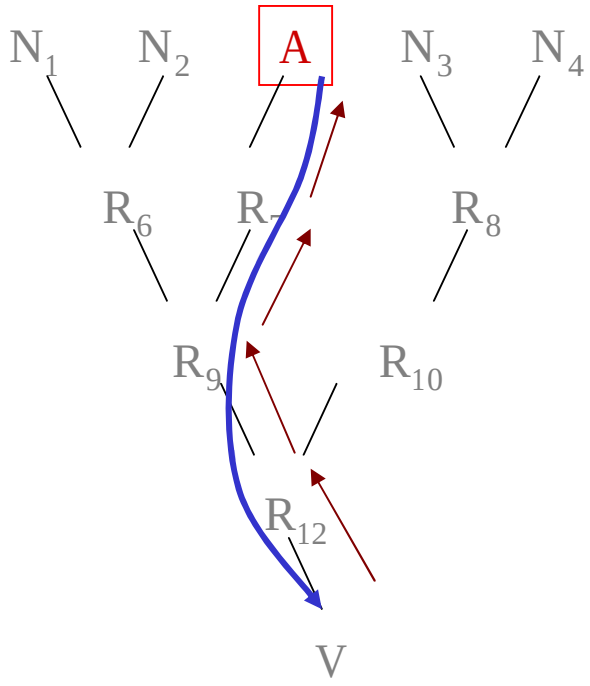
- DoS/DDoS attack can be classified into
  - Software exploitation
  - Flooding-type attack

Our target attack

- Attacker traceback is an essential security component for DoS/DDoS attacks
  - To take a proper countermeasure near attack origin
  - For forensics
  - To discourage attacker in advance

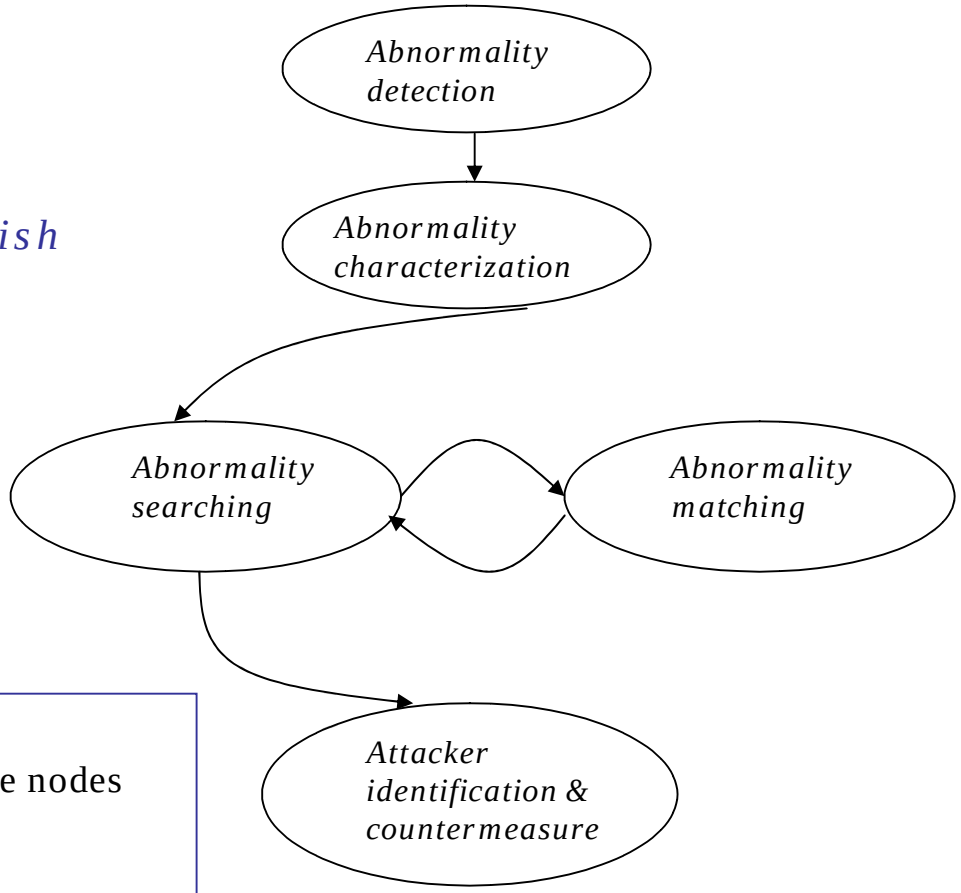
- Wireless multi-hop networks have different characteristics from the Internet, which makes it difficult to directly apply existing attacker traceback schemes to wireless multi-hop networks
  - No infrastructure
  - Dynamic topology (Node mobility, power outage, etc.)
  - Limited network/host resources

On Attacker Traceback



To accomplish the mission

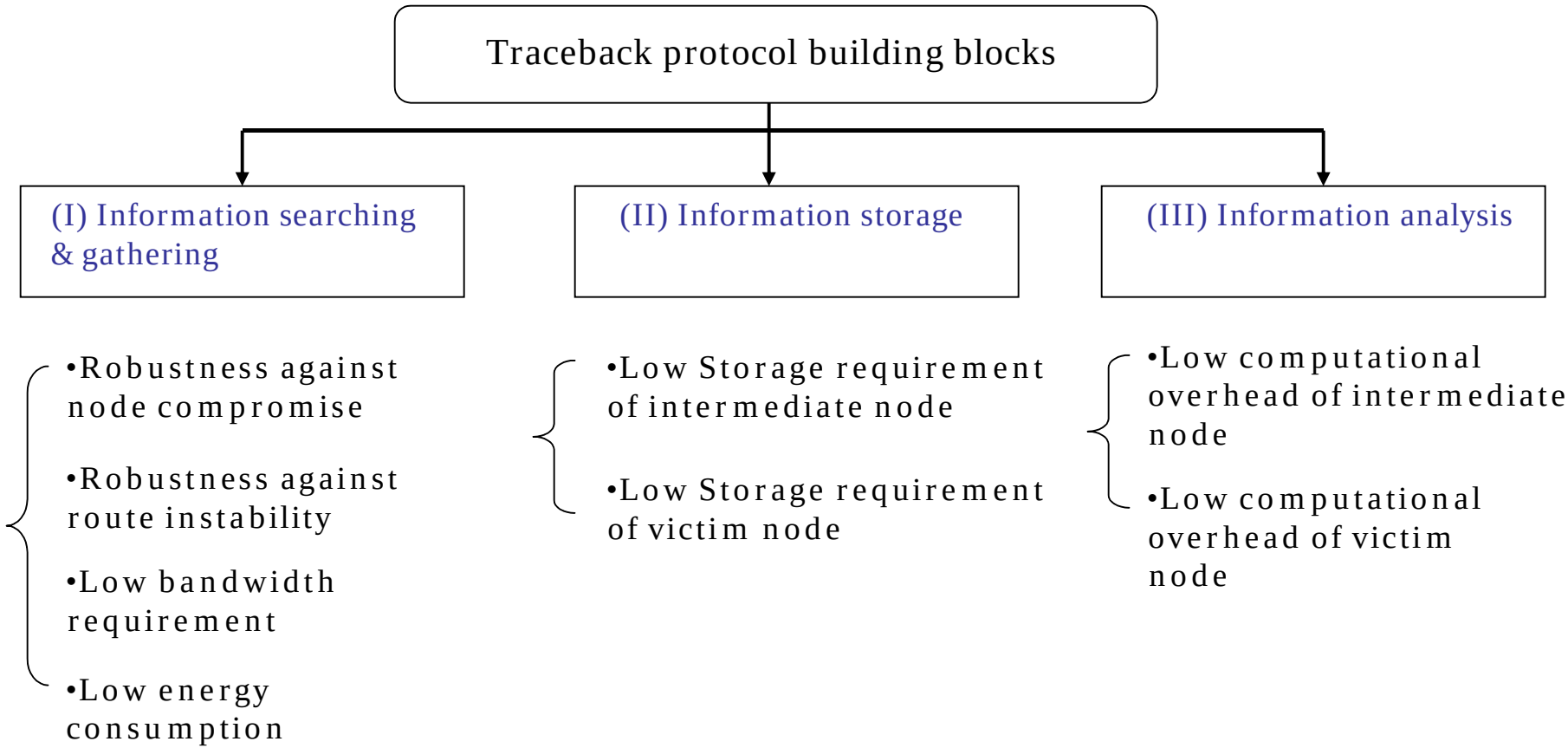
•State diagram for IP traceback



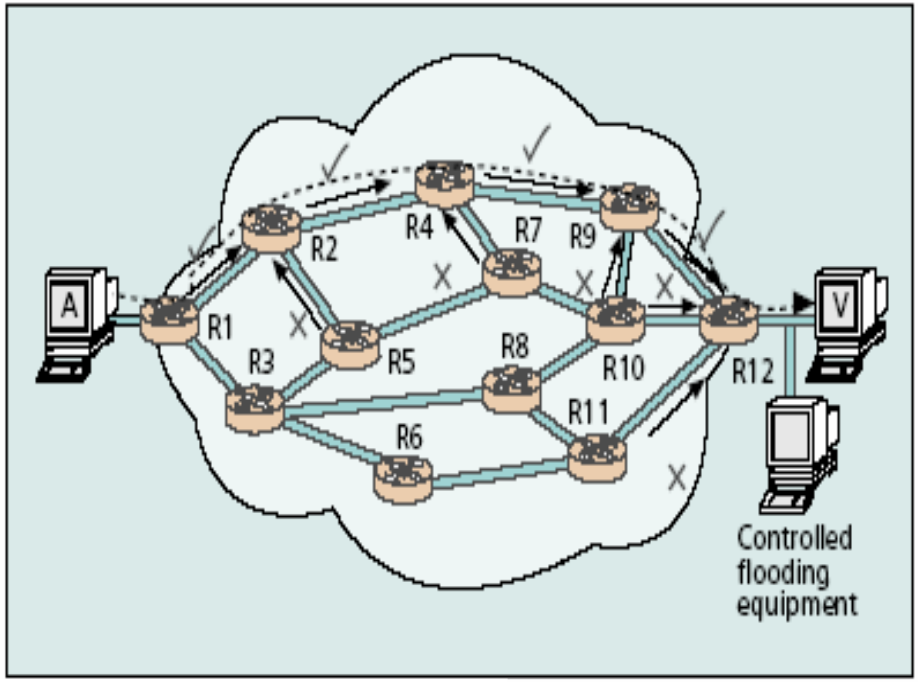
Goal of attacker traceback :

- Identify sequence (time & space) of intermediate nodes carrying the attack traffic
- Identify the neighborhood of attacker(s)
- Identify the attack machine(s)

Requirements Analysis in Wireless Multi-hop Networks



Existing Scheme : (1) Link test



Advantages:

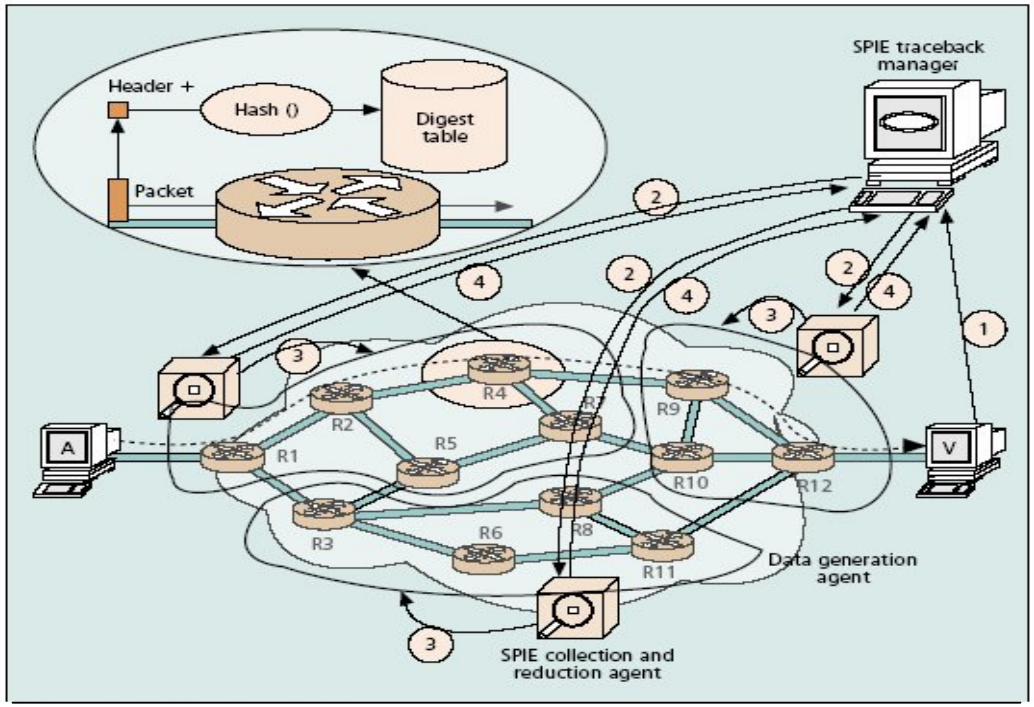
1. No memory overhead
2. Low computational load

Disadvantages:

1. Another form of DoS
2. Traceback needs to be done during attack period
3. Weakness in DDoS attack

*H. Burch, et al, "Tracing Anonymous Packets to Their Approximate Source," Proc. 2000 USENIX LISA Conf., pp.319-327, Dec. 2000

Existing Scheme : (2) Logging-based Traceback



Advantages:

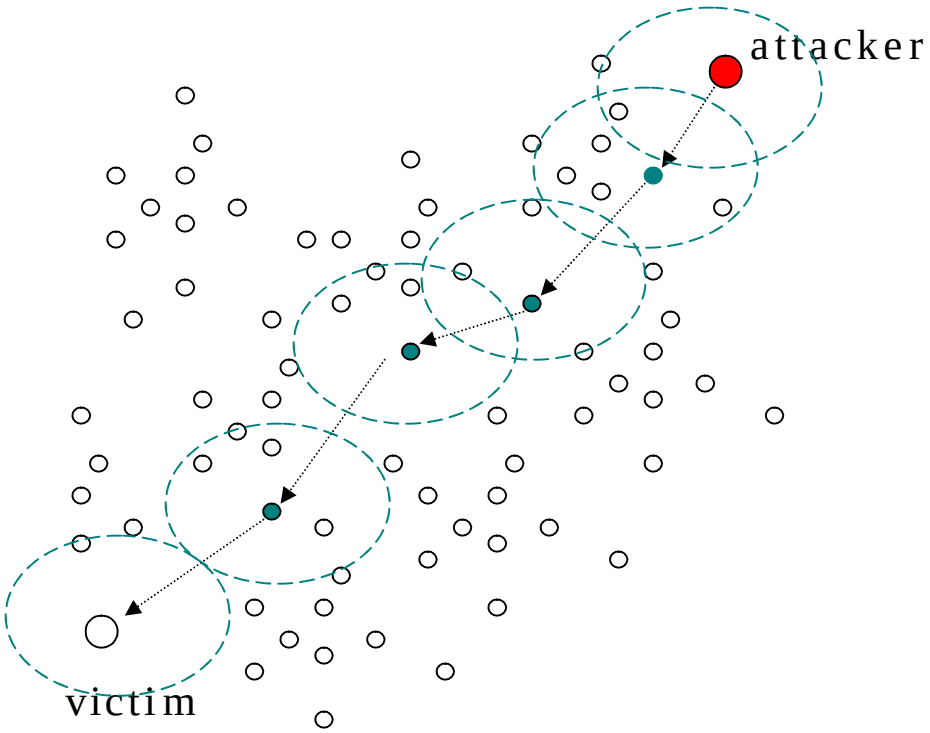
1. Can trace back with single packet
2. Applicable to both DoS and DDoS attack
3. Low bandwidth requirement

Disadvantages:

1. Large storage requirement
2. High processing load

*Stefan Savage, et al., “Network Support for IP Traceback,” IEEE/ACM Trans. On Nets. June 2001

Overall Picture of Our Proposal



We try to solve the following problems.

- How do we characterize attack signature efficiently under address spoofing?
- How do we find the attack path efficiently (vs. flooding or ERS) in large-scale networks?

- Use protocol layer (network, MAC, Cross-layer) abnormality for attack signature characterization.
- Propose (multi-) directional searching and (multi-) directional expanding search, which is based on small-world model

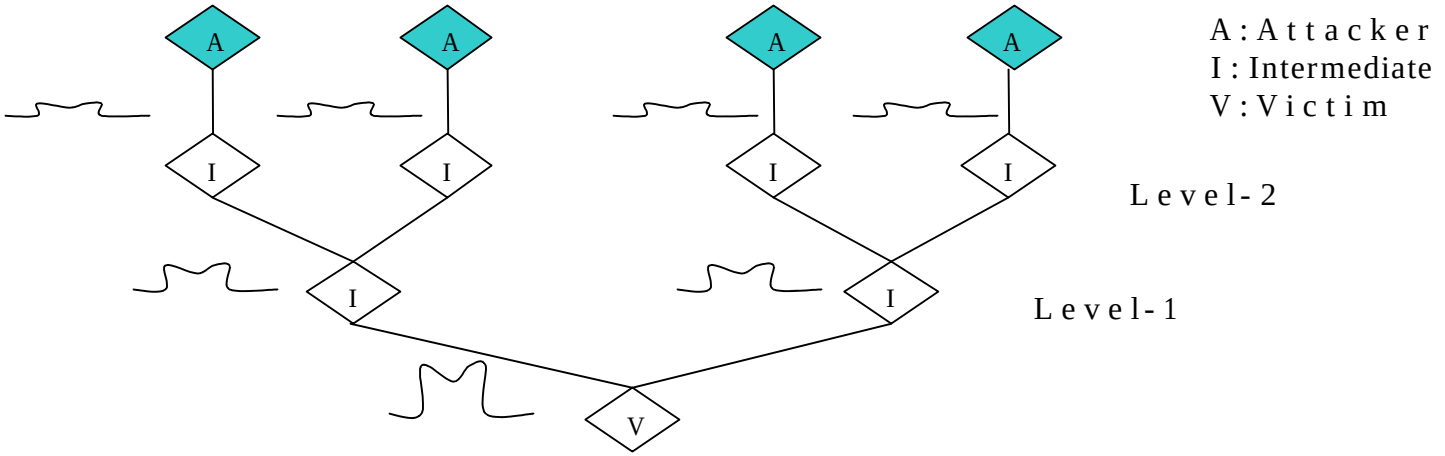
❑ Challenges:

- Under DDoS attack, low level of abnormality is observed near distributed attack origins
- High background traffic lower traffic level or regional abnormality

Problem Definition

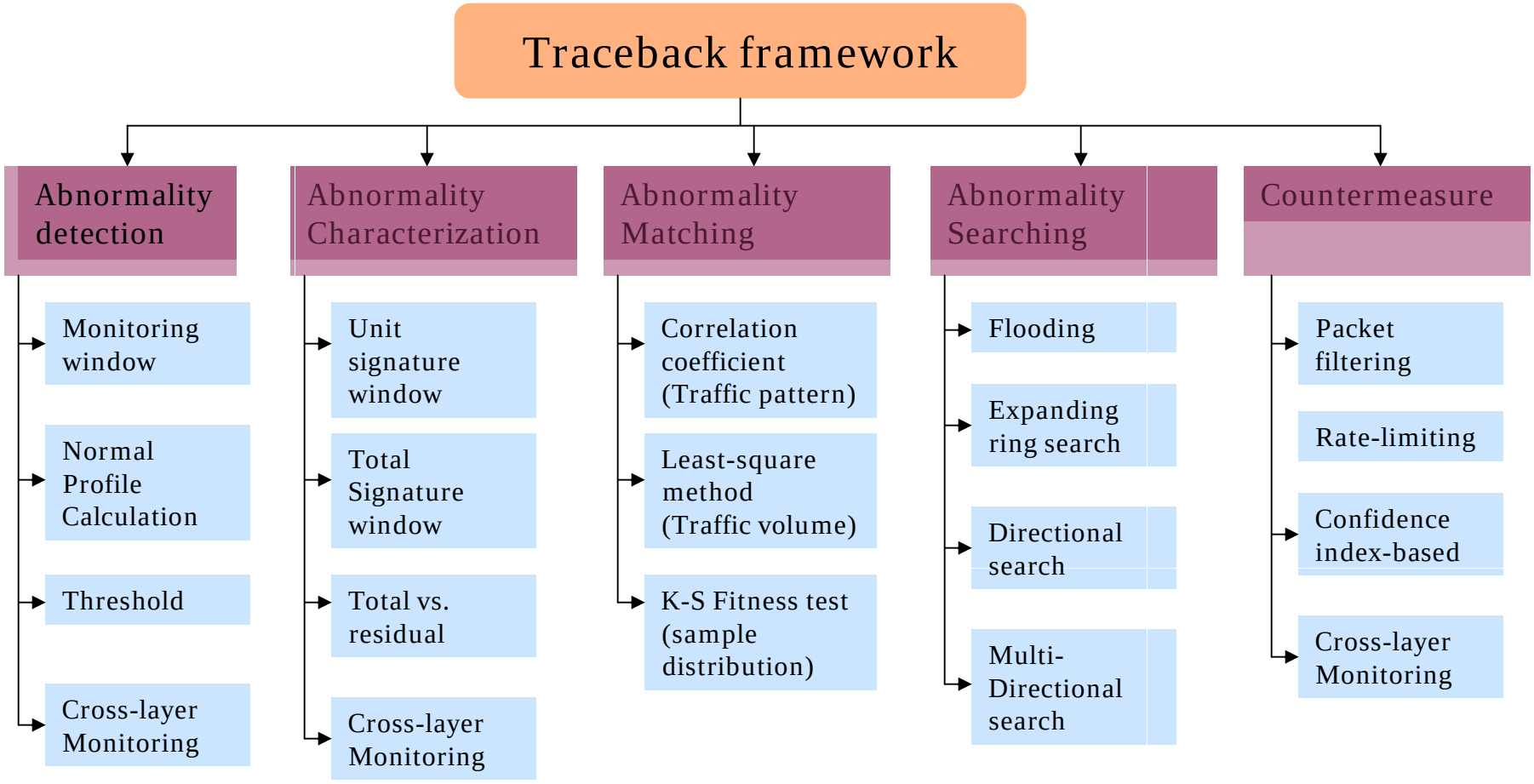
(1) High background traffic can negatively affect the accuracy of abnormality characterization and matching

(2) In DDoS attack, low abnormality is observed near attack origin

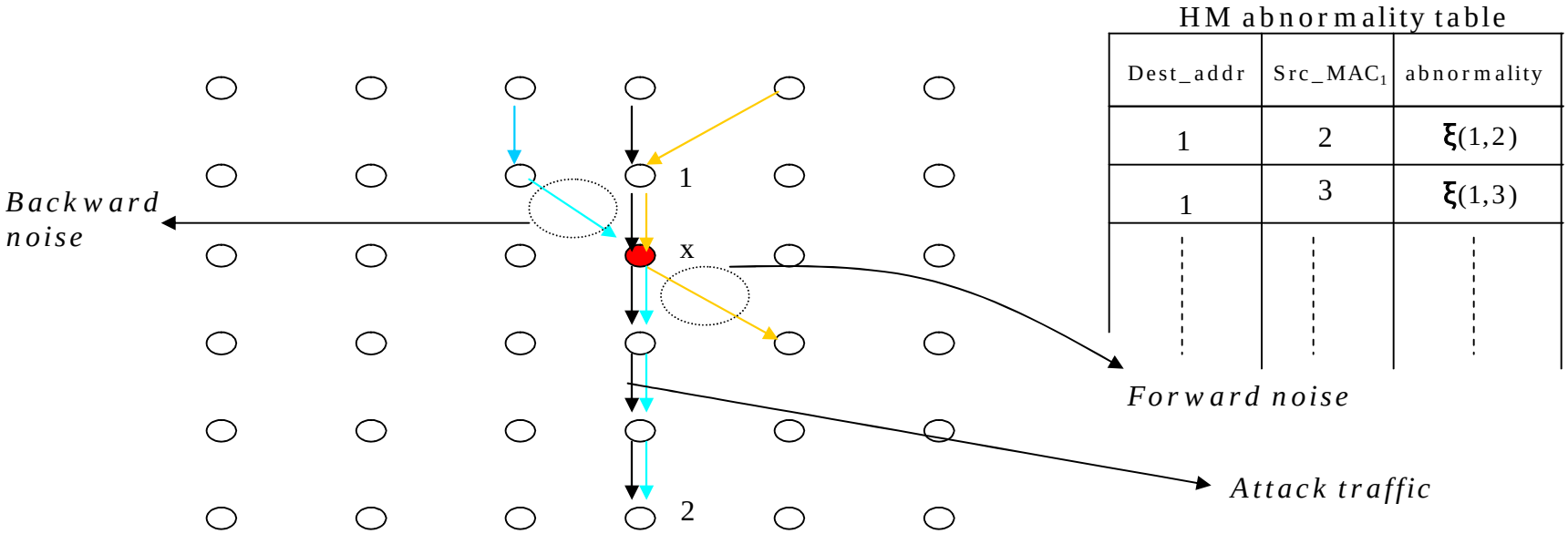


Can be effectively handled by cross-layer monitoring

Overall Traceback Framework



Cross-layer Monitoring



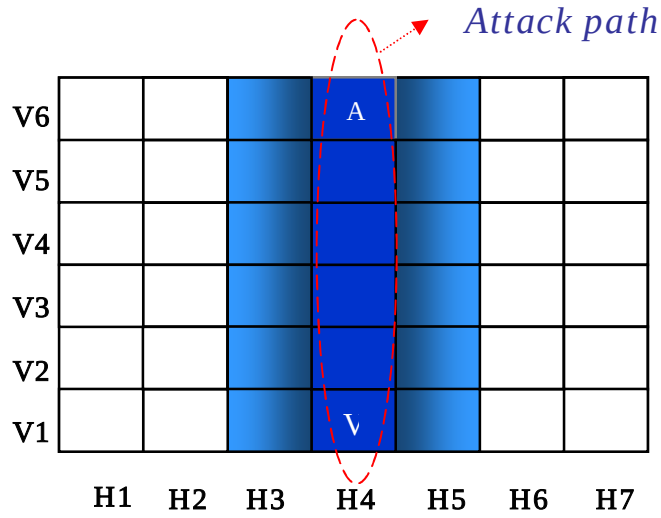
- Both forward and backward noise can be drastically reduced with hybrid monitoring
- Cross-layer monitoring is necessary for efficient abnormality detection, characterization, matching, and countermeasure.

Definition of Signature Energy for Efficient Searching

How do we incorporate all the MAC abnormality information? i.e.,

-Number of abnormality observers
-Abnormality matching level
-Closer contact

We define attack signature energy



* Each cell logically corresponds to contact vicinity

- Attack signature energy is classified as,
  - Individual attack signature energy (atomic unit)
  - Local attack signature energy (to detect attack path region)
  - Global attack signature energy (for analysis purpose)

Cont'd

- Individual attack signature energy observed by node *i*,

$$E_i(t) = \frac{1}{D_i(t)}$$

, Where $D_i(t)$ is the distance between attack signature and candidate attack signature in K-S fitness test

- Local attack signature energy (for protocol/searching purpose)

$$LE(t) = \frac{E^u_{1/2}(t)}{\mu_{1/2}}$$

$$X_{1/2} \equiv Y_{(N+1)/2}$$

$$\equiv \frac{1}{2}(Y_{N/2} + Y_{1+N/2})$$

Where; $\alpha = \frac{n}{N} > \delta$

We use median instead of average to provide robustness against node compromise

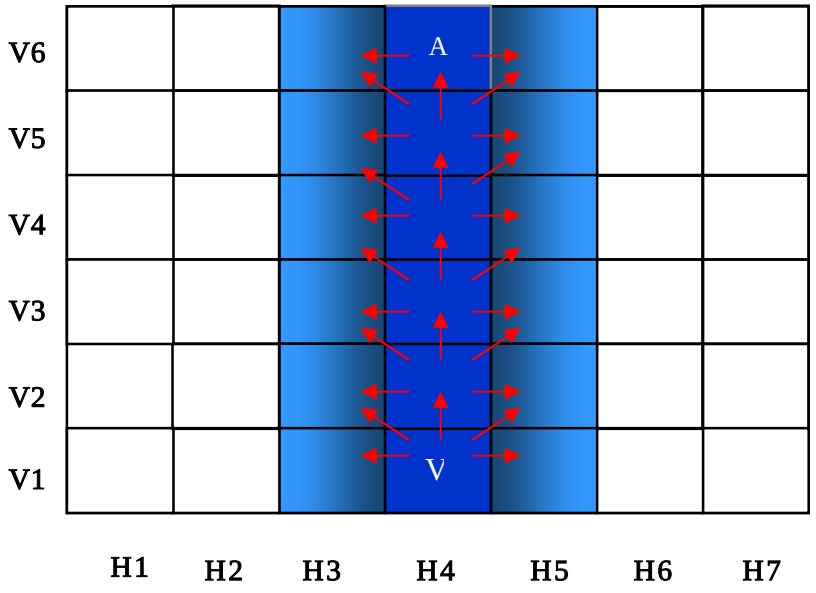
- Global attack signature energy (for analysis purpose) is defined as follows

$$GE(t) = \sum_{i=1}^{n} E_i(t)$$

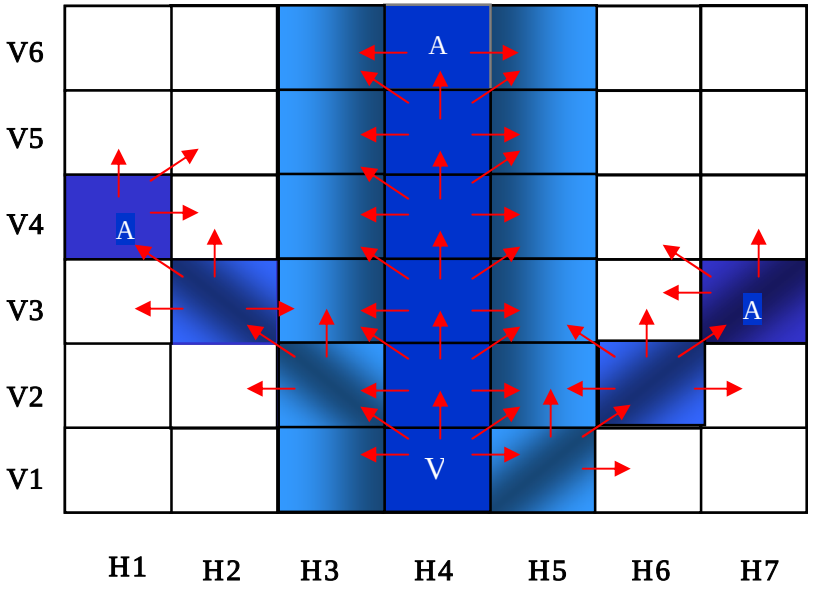
Where, $E_i(t) = \frac{1}{D_i(t)}$

Searching Description

•DoS attacker searching



•DDoS attacker searching



- Local region that shows high signature energy is recursively selected
- In DDoS attacker traceback, combinational test is done

Traceback-Assisted Countermeasure

- After finding closest (one-hop neighbor) nodes to the attacker, countermeasures needs to be taken

- Packet filtering
  - Attack packets are filtered out and dropped at the ingress point
  - ✓ How to distinguish between the good packets and bad packets exactly?

- Rate-limiting
  - Allows a relay node to control the transmission rate of specific traffic flows
  - Rate-limiting mechanisms are deployed when the attack detection has a high false positives or cannot precisely characterize
  - ✓ How much rate we need to limit? – NOT well defined so far

We propose hybrid – between packet filtering and rate-limiting - countermeasure based on abnormality matching level.
Abnormality matching level is quantified by Confidence Index (CI)

Confidence Index (CI)-based Hybrid Countermeasure

- We define attack CI level

  1. CI with TPM/TVM= $r(A, B) \bullet \alpha$

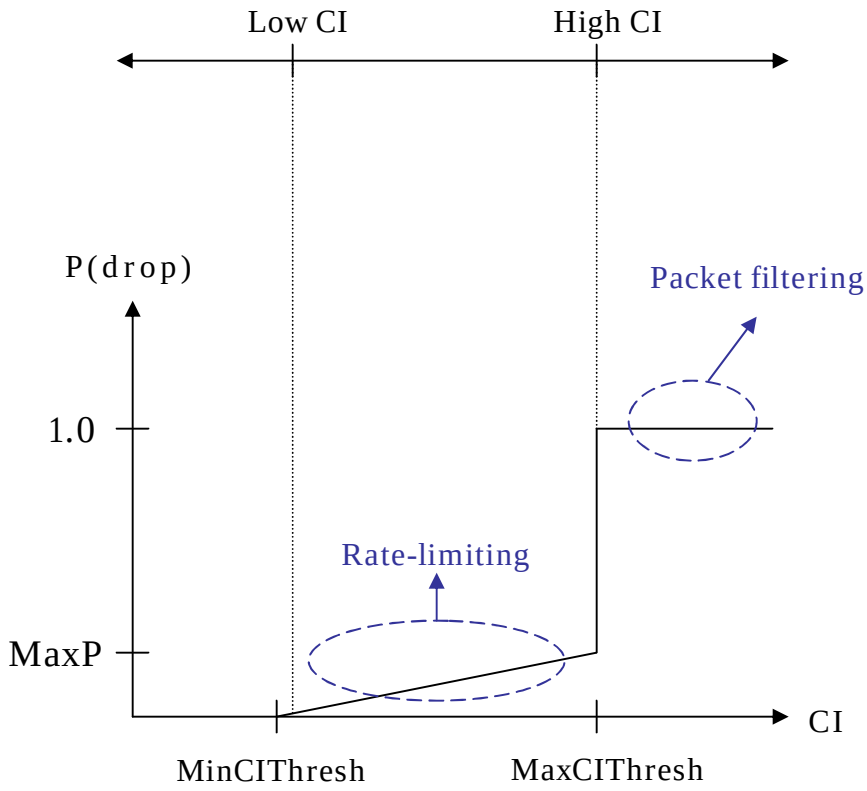
  2. CI with K-S= $\frac{1}{D_n}$

- Based on the CI, rate-limiting level (P) is determined as follows

$$P = MaxP \bullet \frac{CI - MinCIThres\,h}{MaxCIThres\,h - MinCIThres\,h}$$

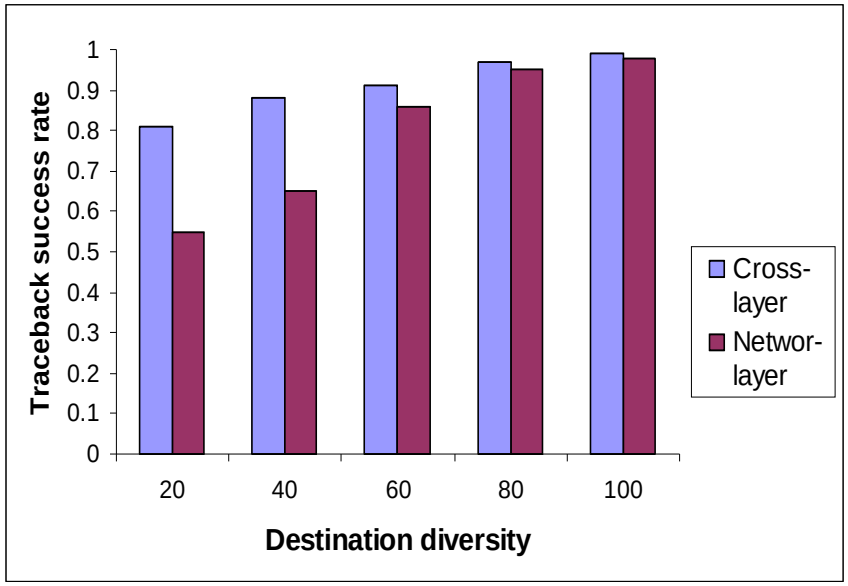
- The scheme reduces to packet filtering, when CI > MaxCIThresh

- Important parameters:
  (1) MinCIThresh, MaxCIThresh, MaxP
  (2) Attack mitigation level
  (3) Negative impact on legitimate traffic

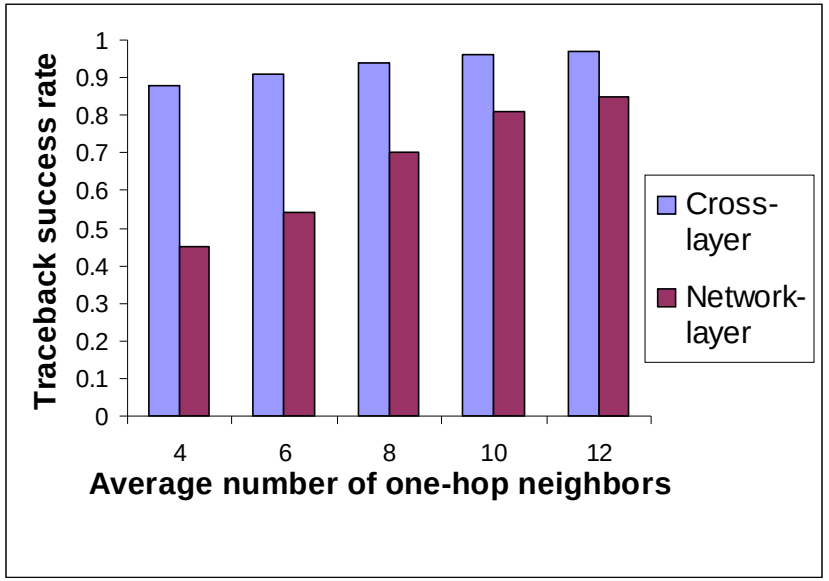


Traceback Success Rate Comparison

- DDoS attacker Traceback success rate comparison (50% background nodes, 6 attackers)



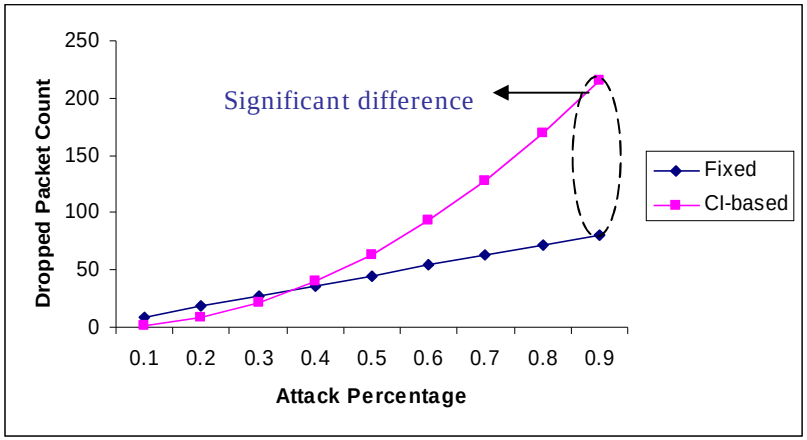
*6 average number of one-hop neighbors

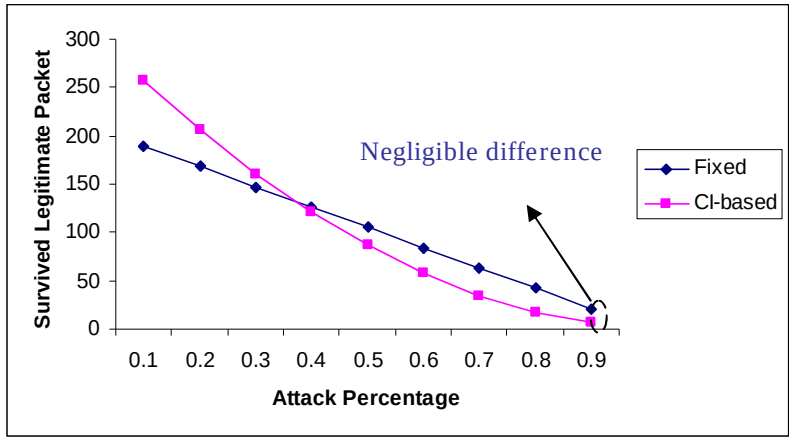


60 destination diversity

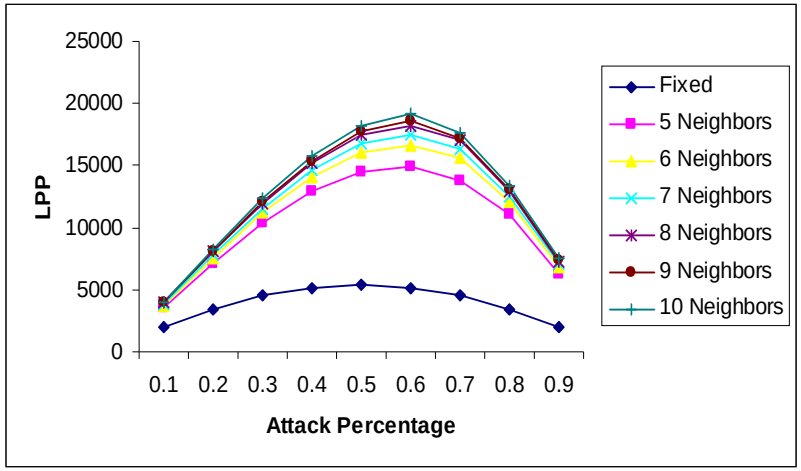
- Cross-layer monitoring-based traceback shows higher performance increase

Countermeasure





•Gain (Dropped attack packet) surpass disadvantage (Lost legitimate packet)



•LPP is the Product of Lost attack packet count and Passed legitimate packet count

•By using CI-based scheme and coarse-grained information, LPP is drastically increased

Conclusions

- We proposed a complete set of attacker traceback framework. (i.e, Abnormality detection, characterization, matching, searching, countermeasure)
- Using Corss-layer Monitoring we can achieve the following merits
  - Robust against high background traffic
  - Robust against DDoS attack
- Use of attack signature energy has the following advantage
  - Robust against node compromise (Majority-voting using MAC layer abnormality overhearing nodes)
- Use of CI-based countermeasure has the following advantage
  - Reduced negative impact on legitimate traffic
  - Increase attack packet dropping efficiency