Achieving High Survivability in Distributed Systems through Automated Response

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Survivable Systems and Intrusion Response

- Ways to make a system survivable
  - At design/implementation phase
    - Eliminate vulnerabilities
    - Policy / Access Control / Cryptography / Software Engineering
      - Challenge : “User Friendliness” (e.g. everybody likes User Access Control in Windows Vista or SELinux ?)
  - In production phase
    - Use IDS to identify misu
      - system logs checkin
        sniffing / virus scanning / V
    - Perform incident/intrusion response
      - Containment and Recovery
      - Stay transparent under normal operations
      - Intervene only when attacks are detected

Intrusion Response System

(focus of this work)

-based root kit detection..

Existing Automated Response System

- Traditional Anti-Virus (AV) Product
  - Scan / Quarantine virus-infected files
- Host-based Intrusion Prevention System (HIPS)
  - An integration of (host-based) firewall, system-level action control, vulnerability detection and sandboxing on top of a traditional AV product.
  - Monitor malicious activities
    - virus, probing from network, attempt to modify critical entries in system registry, visiting phishing websites…
  - Response actions
    - Block access to known phishing websites
    - Quarantine infected files
    - Lock-up internet connection
    - Request user permission to continue on with suspicious activities
  - Norton 360, McAfee Total Protection, TrendMicro Internet Security Pro…

Existing Automated Response System

- Network-based IPS (NIPS)
  - A purpose-built hardware/software to inspect network traffic
    - Content-based detection
      - worm infections / hacks…
    - Rate-based detection
      - for denial of service attack
    - Protocol-analysis
      - existence of large amount of data in the User-Agent field of an HTTP request,…
  - Constantly engaged proactive response actions
    - Rate-limiting, traffic sanitization, IP address / port-number black/whilte-listing
  - Reactive response actions
    - Drop connection, terminate session, update firewall rules
  - Cisco IPS 4200 Series, 3Com Unified Security Platforms, Juniper SSG, …

Existing Automated Response System: Shortcomings

- Stand-alone systems / Minimal collaboration among IDS/ IPS boxes.
  - Attacks against distributed systems cause correlated damages to multiple system components.
  - Correlation of alerts improves both the detection accuracy and the understanding of an attack in distributed systems

Existing Automated Response System: Shortcomings

- Static mapping between detector and response action
  - Example: If "/bin/sh" is detected in network traffic (potential attempt to create a shell), then "black-list the source IP".
    - What if the response is not effective? What if it's a false alarm? What if the created shell only has limited privilege and is not really harmful?
- Pure NIPS or pure HIPS strategy is often not desirable
  - NIPS alone at the perimeter of a system
    - Limited view of attack manifestations
    - False alarm can cause degradation of system performance
    - Some organizations are interested in letting attack propagate through the system till a point when significant damage is imminent
  - HIPS alone inside the system
    - Rely on host data for detection
    - More intrusive to applications
    - Last line of defense

System Model

- BASELINE Model of Automated Response in Distributed Systems
  - A collection of (detectors, response actions) pairs :
    - $\{(D_1,R_1), (D_2,R_2),\ldots, (D_k,R_k), \ldots, (D_N,R_N)\}$
  - For each pair, a mapping $f_k : D_k \rightarrow R_k$
  - f_k is designed based on expert knowledge
- Proposed Model of Automated Response in Distributed Systems
  - The set of all the detectors D and the set of all the response actions R

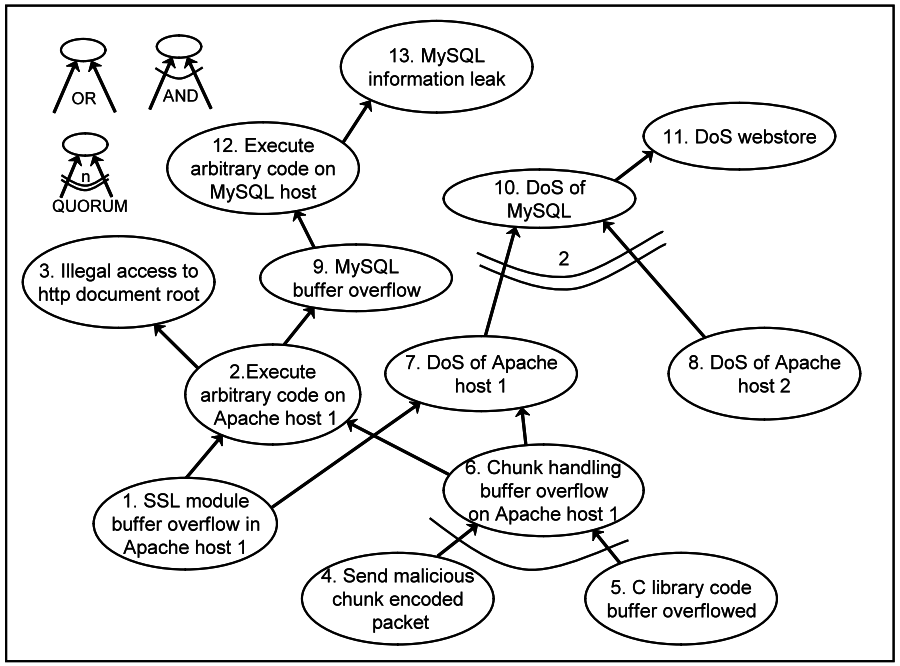
$$D=\bigcup_{k=1}^{N} D_k \quad , \quad R=\bigcup_{k=1}^{N} R_k$$

  - History of past attacks H
  - A mapping $f : (D,H) \rightarrow R$
  - f is designed to maximize expected system survivability based on the information accumulated in H and detectors D
  - f is designed to tolerate new types of attacks

Attack Model: Multi-stage Attack

- Attack originates outside the network
- Each step achieves certain privilege on a service
- Elevated privilege is used to compromise a connected service
- Ultimately some end goal is sought to be achieved

IDS Alert



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Hypotheses

- The proposed model describes a set of responses, from which the expected system survivability is the upper bound of the expected system survivability from any set of responses generated from the BASELINE model.
- In a practical system, it is possible to identify cases when the proposed model yields a higher system survivability than the BASELINE model.
- It is possible that the use of history information in the proposed model can further improve system survivability.

Impact Vector

- A system has transaction goals and security goals that it needs to meet through the time of operation
  - Example: provide authentication service & preserve privacy of sensitive data
- Attacks are meant to impact some of these goals
- Deployed responses also impact some of these goals
  - For example, by temporarily disabling some functionality for legitimate users as well
- Assume the impact can be quantified through a vector Iv
  - Each element in the Iv corresponds to the impact on each transaction/ security goal $\in [0, \infty]$

$$\text{Iv} \quad v_1 \quad v_2 \quad \ldots \quad v_k \quad v_{k+1} \quad \ldots \quad v_m$$

Impact on system transactions Impact on system security goals

Optimality of Response Actions

- We formally define the cost for a response combination (a set of response actions) RC_i as:

$$Cost(RC_i) = | Iv(RC_i) | = \left| \sum_{n_k \in \text{I-GRAPH}} Iv(n_k) \Pr(n_k) + \sum_{r_k \in RC_i} Iv(r_k) \right|$$

$Iv(n_k)$: Impact from reaching an attack step node n_k

$\Pr(n_k)$: Probability of reaching node n_k

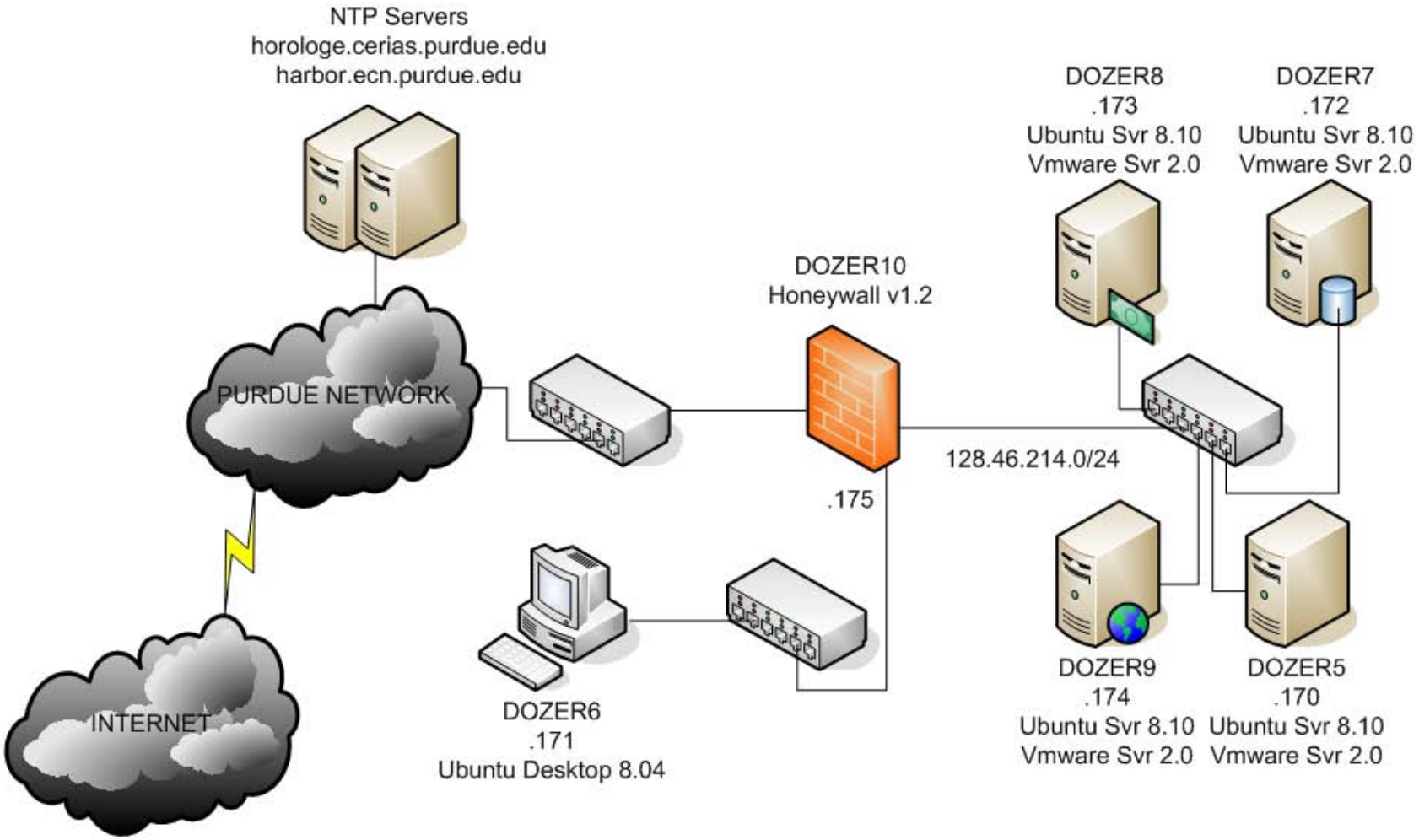
$Iv(r_k)$: Impact from deploying the response r_k

- The response combination RC_i is said to be optimal for a given attack if it achieves the minimal Cost(RC_i)
  - In ADEPTS, optimality achieved "per node and per out-going edge"

ADEPTS: An Unfolding Story

- Exact optimal response determination is NP-Hard
  - Dependencies between responses
- Local optimization of response actions [IJIS 08]
  - Consider the balance between disruptiveness of response and effectiveness of response
- Genetic algorithm for approximate search of globally optimal solution [SRDS 08]
  - Keep good solutions from previously seen attacks
- Current Work: Response combination for zero-day attacks
  - Multiple nodes in the attack graph are not known
  - Multiple edges in the attack graph are not known

How to Validate The Algorithms



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