Disruption Tolerance in a Distributed E-Commerce System

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Outline

- What is disruption tolerance & Motivation
- Adapative Disruption Tolerant System
- Disruption Detection
- Our Approach
- System Design
- Results
- Disruption Containment and Response
- Conclusions

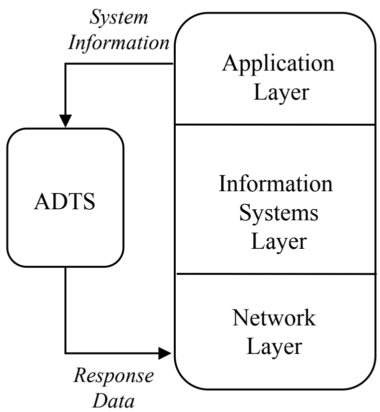
What is Disruption Tolerance?

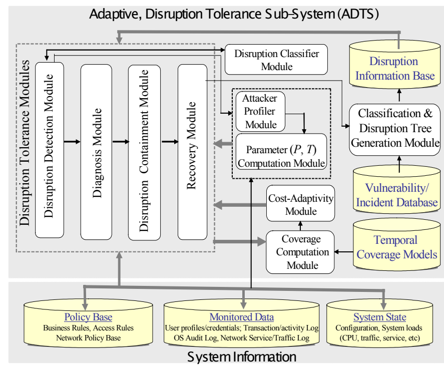
- Causes of system downtime
  - Naturally occurring failures: hardware, software, interfaces
  - Malicious intrusions: internal, external
- Disruption = Failure + Intrusion
- Similarities in approach to tolerate the two causes
  - Both cause system to be unavailable or degraded in functionality
  - Sometimes root cause cannot be distinguished
  - Sometimes response is identical (e.g., take component offline and bring in a diverse spare)
- Dissimilarities in approach to tolerate the two causes
  - Number of coincident events
  - Counter-response

Motivation

- Handling failures and intrusions under same framework gives the following advantages
  - Reduce overhead: Example – A separate detection routine for each sub-system is not required
  - Leverage synergy between two actions: Example – A component that is compromised due to an intrusion need not be recovered from a natural fault
- What is *tolerating* disruption?
  - Not enough to simply detect: Large volume of intrusion detection systems, error detection protocols
  - Need to address the other phases of the process: Diagnosis, Containment, Response
  - The phases are closely coupled in their cost metrics: A pinpointed diagnosis reduces the cost of recovery

Our Approach: Adaptive Disruption Tolerant System (ADTS)



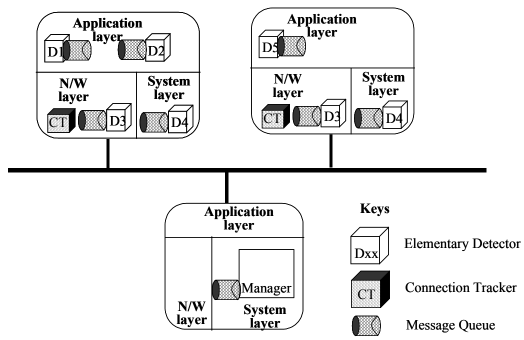


Disruption Detection

- Initial phase of disruption tolerance process
- Based on previous approach to intrusion detection systems (IDS)
- IDSs are based on two alternative choices
  - Anomaly based: Specify the normal behavior
  - Misuse based: Specify the patterns of attacks
- Metrics for evaluating IDSs
  - False positives, or False alarms
  - False negatives, or Missing alarms
- Our approach: **Co**llaborative **D**isruption **D**etection **S**ystems (CODDS)
  - Multiple detectors specialized for different parts of system
  - Manager infrastructure for combining alarms from multiple detectors
  - Rulebase at manager to decide on appropriate response

CODDS Approach

- Motivation
  - Single IDS can have false positives (false alarms) or false negatives (missed alarms)
  - Single IDS is specialized for certain kinds of attacks
  - Timing based correlation from multiple detectors may indicate useful characteristics of attack such as propagation speed



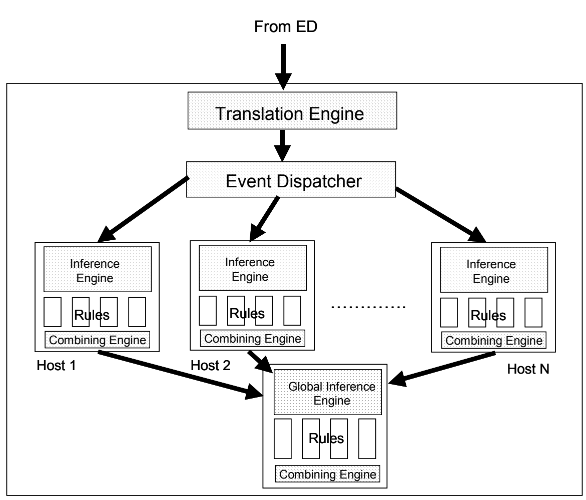
CODDS Components

- Elementary Detectors (EDs): Specialized detectors distributed through the system
  - The EDs maybe off-the-shelf and minimal change is required for integration into CODDS
  - Different hosts may have different configurations of EDs
- Message Queue (MQ): Communication layer for multiple CODDS components
  - Secure through a shared key and hash digest
- Connection Tracker (CT): Kernel level entity to track which process has active connection on which port
- Manager: Workhorse of CODDS responsible for collating alerts from EDs and generating a combined alert which is expected to be more accurate
  - Can take into account local alerts from individual hosts to make a global determination

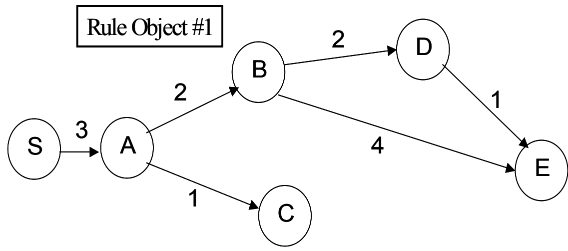
Manager Architecture

- Manager communicates with other entities through MQ and has shared key with each ED
- Manager components are
  - Translation engine: Translates native alert formats into CODDS format
  - Event dispatcher: Dispatches the event to the appropriate host's Inference Engine instance
  - Inference Engine: Matches the received events against the Rule Objects to come up with a determination of disruption.
    - A separate instance of the Local Inference Engine for each host
    - A Global Inference Engine for correlating the results from the local engines
    - Rule Objects store the rules, one for each class of disruption
  - Combining Engine: If multiple types of inference engine, this combines the detection decision from each

Manager Architecture



Graph-Based Inference Engine



- Rules are represented as graphs
- Nodes are events and Edges represent sequencing of events
- Edge weights represent assurance values indicating likelihood of sequence

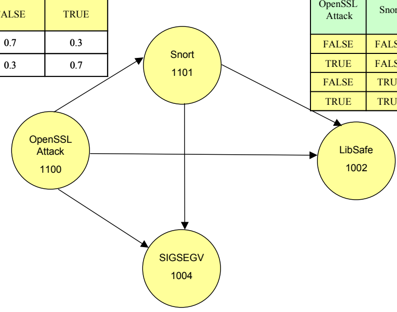
- Assurance Value (AV) for a disruption given by sum of edge weights
- An event is matched with a rule object if it is *fusionable*, i.e., belongs to the same disruption instance
- Discounted Assurance Value (DAV) for partial matches

$$DAV = AV \times (Partial\ path\ length/Complete\ path\ length)$$

Bayesian Network Based Inference Engine

- In a Bayesian Network, the nodes represent random variables and edges the direct influence of one variable on another
- Three step process for creating rule object
  - Nodes to represent events
  - Edges to represent conditional probability relations among the events
  - Creation of table with conditional probability values

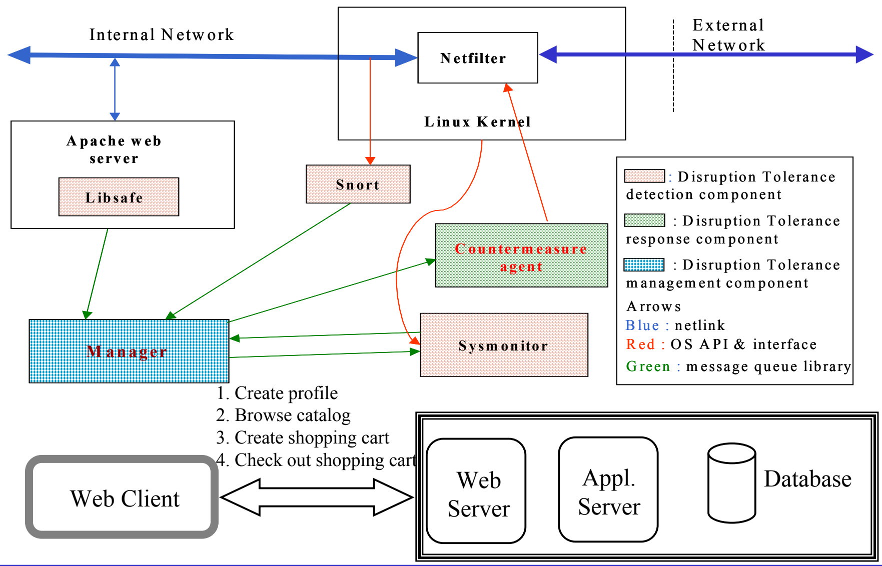
OpenSSL Attack	Snort	
	FALSE	TRUE
FALSE	0.7	0.3
TRUE	0.3	0.7



OpenSSL Attack	Snort	LibSafe	
		FALSE	TRUE
FALSE	FALSE	0.9	0.1
TRUE	FALSE	0.3	0.7
FALSE	TRUE	0.8	0.2
TRUE	TRUE	0.1	0.9

- Bayesian Network toolbox used for solving
- Input is fusionable event stream
- Output is conditional probability of root (the disruption)

CODDS System: Current Implementation



CODDS Elementary Detectors

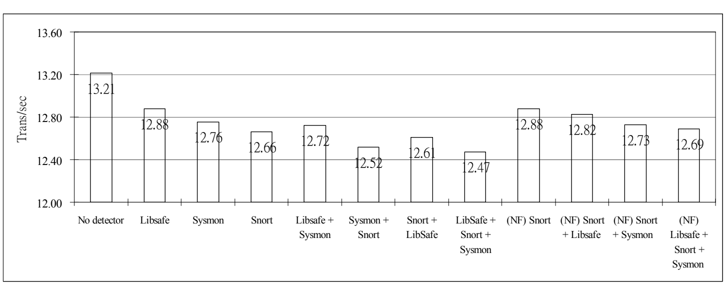
- Application level: *Libsafe*. Middleware to intercept “unsafe” C function calls and prevent stack overflow attacks.
- Network level: *Snort*. Sniffs on incoming network packets and matches against rulebase to perform misuse based detection.
- Kernel level: *Sysmon*. Home-grown new detector.
  - Intercepts system calls for file accesses and executions.
  - Takes a set of rules for disallowed accesses or executions
    - Can be specified using wildcards or directory tree
  - Intercepts signals of interest that can flag illegal operations.
    - SIG_SEGV to indicate segmentation violation that may be caused by buffer overflow

Simulated Disruptions

- Disruptions which are of type intrusions are simulated for our experiments.
- Three classes of disruptions, multiple types within each class, and multiple variants within each type
  - Buffer overflow: Can be used to overwrite parts of stack and write and execute malicious code
    - Apache chunk attack
    - Open SSL attack
  - Flooding: Overwhelm the network with redundant or malicious packets causing a denial of service
    - Ping flood
    - Smurf
  - Script based: Exploit poorly written scripts which do not do input validation to execute arbitrary commands
    - Used unchecked *open()* and *system()* calls

Results: Performance – Without Disruptions

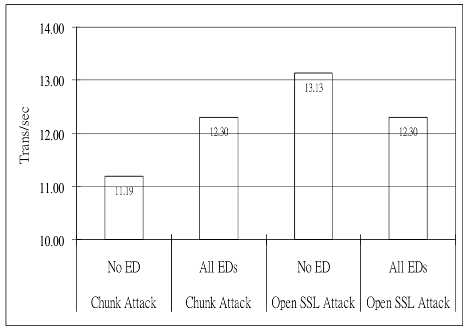
- Measured without and with disruptions
- 30 web clients running concurrently
- Transactions per second of workload transaction measured
- When multiple EDs present, manager with both Inference Engines is deployed



No Disruption

- Degradation overall: 3.95% with Snort rules modified, 5.60% without
- Degradation due to Sysmon alone: 3.46%

Results: Performance – With Disruptions



- OpenSSL Attack performance degradation is 6.33%
- Chunk Attack performance improves!!!
  - Having Libsafe prevents core dumping
- Highest performance degradation due to Matlab Bayesian Network toolbox

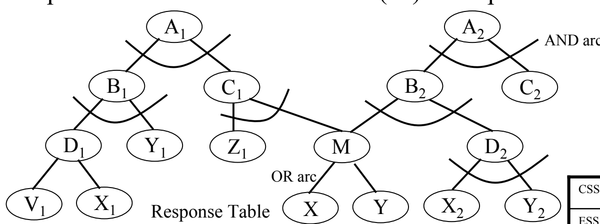
Results: Accuracy of Detection

	Snort	**Libsaf e**	**Sysmon (Signal)**	**Sysmon (File)**	**CIDS**
No attacks	Yes (1807,1933)	No	No	No	No attack
Open SSL	Yes (1881,1887)	No	Yes	*R1*	Yes
Open SSL variant	No	No	Yes	*R1*	Yes
Apache Chunk	Yes (1807, 1808, 1809)	Yes	Yes	*R1*	Yes
Smurf 1000	Yes (499)	No	No	No	Yes
Smurf 500	No	No	No	No	No
Ping Flooding	Yes (523, 1322)	No	No	No	Yes
Script	No	No	No	Yes	Yes

- Yes: Detected. Figures in parentheses are the rule numbers within Snort. Sysmon(File) is the file access detection part, Sysmon(Signal) is the illegal signal detection part; R1: The attack was not successful in creating a file.

Disruption Containment & Response

- Representation model used is Disruption DAG
- Algo #1: Compute the Compromised Confidence Index (CCI) of each node and classify it as candidate for response
- Algo #2: Decide on response based on CCI of node, Disruptivity Index (DI) of response and Effectiveness Index (EI) of response action



CSS	{S1,S2}
ESS	{S3,S4,S5}

Response Table

Node Class	*Response*	*Disruptivity Index*
SC	R1	$\delta 1$
WC	R2	$\delta 2$
VWC	R3	$\delta 3$
NC	R4	$\delta 4$

Conclusion

- Goal is to provide tolerance for causes of system downtime, be it natural failures or malicious intrusions
- Detection is the first phase and is best done by using multiple specialized detectors and combining their alerts into a system wide alert
- The combined alert is shown to be more accurate and efficient
- A CODDS Manager designed for the system
- A distributed e-commerce based platform used for demonstration
- Simply detection is not enough, containment and response are subsequent phases that are also important