Attack Graph Generation for Optimal Sensor Placement

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24 October 2019

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Problem Statement

- To performance comprehensive literature survey on *Attack Graphs* and implement a system for automatically generating an attack graph.

Outline

TVA

- Analysis of vulnerabilities and building a complete map showing all possible paths of multi-step penetration into the network, organized as an attack graph, is known as Topological vulnerability analysis.
- Single vulnerability may not pose a threat but combination of vulnerabilities may allow attackers reach critical network assets.
- TVA considers dependencies among vulnerabilities and combines them in a real way as real attackers might do.

Outline

Adjacency Matrix Visualization

- Attack graph of n vertices can be represented by matrix of n x n.
- Rows and columns of matrix can be placed in any order, but orderings that capture regularities are desired.
- Regularities include cluster of vertices that have a common edge.
- Adjacency matrix shows reachability within single step.
- Adjacency matrix raised to power of P gives number of p-step paths between vertices.

Contd.

- Native Matrix multiplication can be improved by spectral decomposition of A into V and D.
- D contains eigen values as diagonal elements and V is matrix of eigen vectors. Now, Large powers of A can be computed by raising D to large powers.
- Transitive closure of A gives for each pair of vertices, whether attacker can reach one graph vertex to another over all possible number of steps.
- Reachability matrix contains minimum no. of steps required to reach one vertex from another.

Outline

Introduction

- No widely accepted security metrics
- Every metric is qualitative rather than quantitative
- 3 factors that account to quantitative security metrics are
  (i) *Significance of resource* - Prioritizes the resources
  (ii) *Reconfiguration cost* - Provides the relative overhead for network hardening
  (iii) *Attack Resistance* - Removes the idea of qualitative measure.

Outline

Probabilistic Security Metrics

- It gives the likelihood of an attack
- For each exploit e and condition c we will be having individual probabilities p(e), p(c) and cumulative probabilities P(e), P(c).
- Individual probability is the likelihood of exploiting exploit e given all it's preconditions are satisfied.
- Cumulative probability represents the likelihood of reaching a state in which attacker can successfully exploit a given exploit.

Cummulative Probability

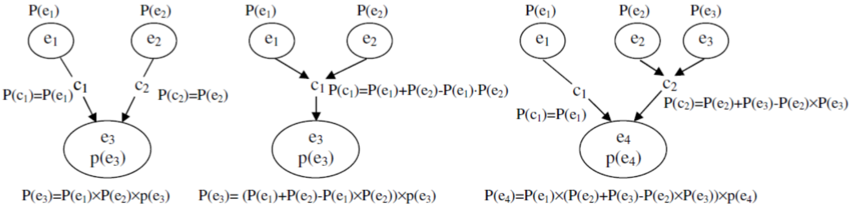


Fig. 2. Examples Showing the Need for Cumulative Scores of Conditions

[7] Wang, L., Islam, T., Long, T., Singhal A., & Jajodia, S. (2008, July). *An attack graph-based probabilistic security metric.*

Probabilistic Security Metrics

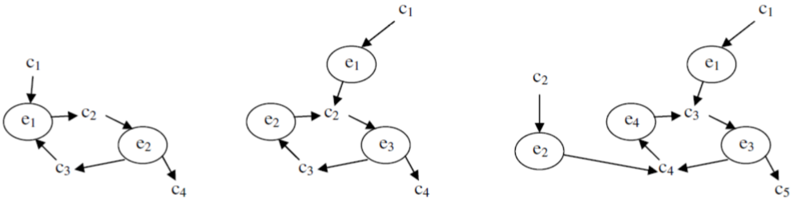


Fig. 3. Cycles in Attack Graphs

[7] Wang, L., Islam, T., Long, T., Singhal A., & Jajodia, S. (2008, July). *An attack graph-based probabilistic security metric.*

Probabilistic Security Metrics

- We follow 3 methods to avoid difficulties
  a) Remove cycles.
  b) Break edges
  c) Neither remove cycles nor break edges

Outline

Attack Resistance

- Metrics are quantified based on the time and effort taken to compromise a given critical resource
- More the no.of attack paths the less secure is the network.
- Metrics are quantified by
  (i)Assigning the real number values to attack resistances
  (ii)Attack resistances are represented as set of intial conditions.

Real values assignment

- The attack resistance is quantified by a real number
- For an exploit e the attack resistance value is denoted by r(e)
- Cumulative attack resistance is similar to that of effective resistance in an electrical circuit
- Cumulative attack resistance is calculated using $\oplus$, $\otimes$ between two resistances.
- $1/r1 \oplus r2 = 1/r1 + 1/r2$ - parallel condition
- $r1 \otimes r2 = r1 + r2$ - series condition
- $R'()$ function gives the modified attack resistance values when a particular exploit occurs.

Set of Initial Conditions

- Attack resistance is completely different from the previous approach
- Resistance here means set of initial conditions to be satisfied before an intrusion is possible.
- More the no.of initial conditions more the resistance

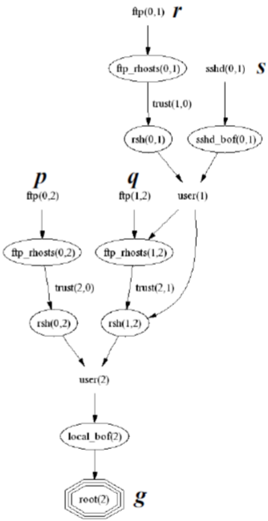
Outline

Network Hardening

- This is one of the first method to quantify the metrics
- Vulnerabilities should not be taken in isolation
- Every exploit is represented as a Boolean value and attack path is represented as a function of these Boolean values
- We start building a dependency graph with initial conditions as post conditions.
- In forward building of dependency graph we avoid redundancies by avoiding cycles.
- Once we reach the goal we do a backward processing in order to get those states that are not reachable from initial state but are relevant to the attack goal.
- This results in a set of minimal attack paths.
- $g = p + qr + qs$
  $=(p+q+r+s).(p+q+r+s').(p+q+r'+s).(p+q+r'+s').(p+q'+r+s)$

Outline

Examples for Hardening



[8] Noel, Steven, et al.*"Efficient minimum-cost network hardening via exploit dependency graphs."*

Outline

Correlating Intrusion Events

- Network vulnerability is ignored in most of the cases
- Joint model of attacker exploit and network vulnerability is created.
- Graph distance between the events is used to measure the correlation between the events.
- If an event is unreachable from previous one then it will be taken as a new event.

Correlating contd

- For easy calculations we take inverse of distance as it lies in the range of [0,1]
- We pass this distance function through an exponential weighted function in-order to take care of false alarms.
- This exponential weighted function is called low-pass-filter function.
- After passing through low-pass filter threshold value helps us to correlate the events.
- if d_k is the distance between events then consider

$$x_k = 1/d_k$$

$$\bar{x_k} = P.\bar{x_{k-1}} + (1-p)x_k \quad 0 \leq p \leq 1$$

$\bar{x_k}$ represents the filtered version of original sequence

[6] Noel, Steven, Eric Robertson, and Sushil Jajodia. *"Correlating intrusion events and building attack scenarios through attack graph distances."*

Outline

Sensors

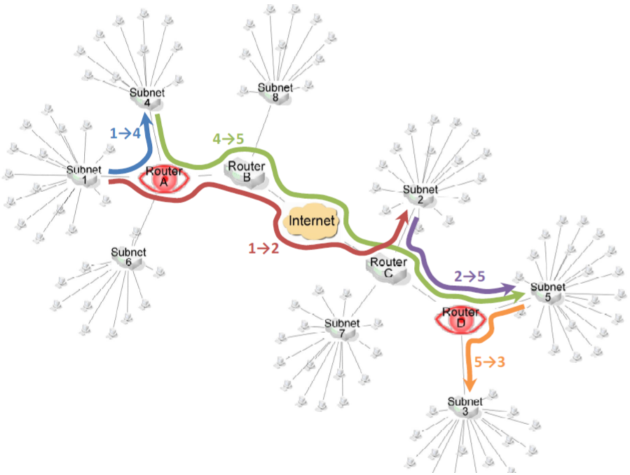
- Traditionally sensors are placed at network perimeters.
- Sensors report all malicious traffic without any regard to actual network configuration, vulnerabilities and mission impact.
- To reduce false alarms, attack graphs are built based upon network configuration, vulnerabilities and attacker exploits.
- Sensors are placed in minimal number to protect mission critical assets.

Outline

Sensor Placement

- Even though firewalls,routers ACLs are present still residual vulnerabilities are present.
- To minimize costs, Minimum no of sensors are placed to cover all critical paths. This is an instance of NP Hard Problem.
- Greedy algorithm for NP Hard Minimal set cover problem gives polynomial time solution.
- Algorithm is as follows
  - At every stage, select the set with large no. of elements.
  - If there are more sets with equal large no. of elements, select the one with more infrequent elements.

Optimal Sensor Placement



[9] Noel, Steven, and Sushil Jajodia. *"Optimal ids sensor placement and alert prioritization using attack graphs."*

Outline

Alarms Prioritization and Attack Response

- Attack graphs are used to correlate IDS alarms, prioritize them and predict the future steps and respond accordingly.
- Attack origin and goal can be predicted from alarms and adjacency matrix.
- For an alarm, non-zero elements along the projected row show all possible single steps forward. Projection along column gives attack origin.
- Alarms are prioritized based on distance from critical networks assets. Closer to critical assets are given higher priority.
- If attack is detected, we can predict the next steps and block that particular machines and ports

For Further Reading I

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Thank You