Bootstrapping Trust in a “Trusted” Virtualized Platform

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Introduction

Working with untrusted computers is often not possible

Trust is a known factor for adoption and proliferation

Computers need reliable roots of trust

Trust establishment is enabled by TPM as root of trust
The TPM can be used to establish trust in a system.
Verifier is interested in virtual environment

Security properties of virtual environment directly depend on virtualization system

Verifier needs to establish trust in virtual environment

Verifier needs to establish trust in virtualization system
TPM doesn’t scale with virtual environment

TPM is used to establish trust in virtualization system

Use vTPM as a root of trust for virtual environment
TPM can be used to establish trust in VMM.
Can vTPM be used to establish trust in Virtual Environment?
Agenda

Introduction

Background

Goldeneye Attack

Discussion & Conclusions
Background and Model
Virtualization System (VS) enables execution of multiple computing systems on the same hardware.

... is a collection of components required to reach the desired virtualization target.

... supports the virtual platform.
Background and Model

- Process (App)
- Operating System (OS)
- Virtual Machine (VM)
- Virtual Machine Manager (VMM)
Background and Model

TPM implements several system roots of trust

TPM effectively allows trust establishment in system state

vTPM serves as root of trust for a virtual machine

vTPM is essentially a program and a VS component
In summary,

Hardware + TPM forms a “trusted” platform

Virtualized Platform + vTPM forms a virtualized “trusted” platform
Goldeneye Attack
Stated goals of Virtualized Trusted Platform are:

- Enable a verifier to obtain (...) information about the security state of the virtualized environment

- Enable a verifier to obtain (...) information about the security state of the underlying virtualization system providing isolation and resources to the virtualized environment
Goldeneye Attack

a) Example attack using a weak vTPM - VM association.
Goldeneye Attack

Goldeneye adversary has limited control over association

vTPM carries VM trust information

TPM carries VS trust information

Verifier establishes trust in the wrong but good system

b) Logical equivalent of a weak association.
Goldeneye Attack

Changing virtual Root of Trust

Adversary clones or fabricates vTPMs
Place or copy system states in vTPM
→ Allows trust establishment in a untrustworthy VM

Changing physical Root of Trust

Similar to Cuckoo attack [18]
vTPM has reference to TPM
Adversary associates a VM with vTPM on another Virtualization System
→ Allows trust establishment in another VS
Goldeneye Attack

Exploits architectural gap in the design of virtual trusted platform

Verifier queries vTPM about VM state and eventually VS state

Relies on “strong association” between vTPM and VM [3,7,8,23]

Association itself is not verifiable nor enforceable by trusted elements

b) Logical equivalent of a weak association.
Goldeneye Attack

- Informal model of virtualized trusted platform
- Outline Goldeneye attack and effects
- Describe path towards executing the attack
Goldeneye Attack

Formal system model

Formalization of flawed trust establishment

Show that attack works and trust establishment does not
Goldeneye Attack

Graphical view of Virtualization System

Describe space and motion independently

Today we discuss *placing* and *linking*

Bigraph [17] as foundation and notation

Reasoning strategy for dependencies in the system graph
Goldeneye Attack

Proof strategy for Goldeneye

Axioms for Trusted Computing System

Axioms for Trust Establishment

Assume an untrustworthy system

Show that axioms and assumption lead to trusting an untrustworthy system

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trusted(_A)(a)</td>
<td>Agent (a) is trusted</td>
</tr>
<tr>
<td>SaysSecure(_a), (_e)</td>
<td>(a) says element (e) is secure</td>
</tr>
<tr>
<td>Trusted(_VS)((_vs))</td>
<td>(_vs) is trusted</td>
</tr>
<tr>
<td>On(_tpm), (_m)</td>
<td>TPM (_tpm) is on (_m)</td>
</tr>
<tr>
<td>Trusted(_TPM)((_t))</td>
<td>TPM (_t) is trusted</td>
</tr>
<tr>
<td>Trusted(_VTPM)((_vtpm))</td>
<td>vTPM (_vtpm) is trusted</td>
</tr>
<tr>
<td>Bound(_vtpm), (_vm)</td>
<td>vTPM (_vtpm) is bound to (_vm)</td>
</tr>
<tr>
<td>SaysBound(_vm), (_vtpm)</td>
<td>(_vm) says (_vtpm) is bound</td>
</tr>
<tr>
<td>Trusted(_VM)((_vm))</td>
<td>(_vm) is trusted</td>
</tr>
</tbody>
</table>

\[
\forall a,e \: \text{Trusted}_A(a) \land \text{SaysSecure}(a,e) \supset \text{Secure}(e)
\]

\[
\forall t,m \: \text{On}(t,m) \land \text{Secure}(m) \supset \text{Trusted}_{TPM}(m,t)
\]

\[
\forall \text{vm}, \text{vtpm} \: \text{Secure}(	ext{vm}) \land \text{SaysBound}(	ext{vm}, \text{vtpm}) \\
\supset \text{Bound}(	ext{vm}, \text{vtpm})
\]

\[
\forall \text{vtpm}, \text{vm} \: \text{Bound}(	ext{vtpm}, \text{vm}) \land \text{Trusted}_{VTPM}(m, \text{vs}, \text{vtpm}) \\
\supset \text{Trusted}_V(M, m, \text{vs}, \text{vm})
\]

\[
\forall t, \text{vs} \: \text{Trusted}_{TPM}(m, t) \supset \text{Trusted}_V(S, m, \text{vs})
\]

\[
\forall t, \text{vs}, \text{vtpm} \: \text{Trusted}_{TPM}(m, t) \land (m, \text{vs}, \text{vtpm}) \\
\supset \text{Trusted}_{VTPM}(m, \text{vs}, \text{vtpm})
\]
Goldeneye Attack

Generic model for virtualization systems

Predicate logic for trust establishment

Link system graph with predicate system

Proof of two related attacks on weak vTPM-VM association
Discussion & Conclusions
Virtualizing the TPM originally proposed in 2006 as example

Cited and adopted widely in related research

Each VM gets vTPM instance

Manager inside a Virtualization System domain “handles” all aspects of vTPM instances
Deconstructed into components and hosting systems

We use $x$ to denote open links

A site is where components can be placed ...

... open links work as additional interfaces
Expressing the system state by assembling the component graph

Adding the vTPM manager into the picture

This shows pictorially (and algebraically) that all possible instances of VMs and vTPMs are joined similarly

—> vTPM-mgr has to be trusted

—> we can not verify the association based on some evidence or information
**Discussion**

**Trust by default**
- No changes, just awareness
- Complexity and attack surfaces make this difficult

**Remove malware on systems**
- Only need to worry about VM
- Hard
- Circular
- Still need to verify or trust

**Remove interfaces**
- May help to prevent dynamic re-provisioning of vTPM
- Still need support to change VM and vTPM location and addresses

**Confining Adversaries via Measurements**
- Record co-location of VM and vTPM
- Record transactions such as provisioning and migration of vTPM
- Recording *kind* of vTPM (binary) not helpful, we need direct information about instances
- Frequent PCR updates
- Reporting of client info to arbitrary challengers
Discussion

Unikernel vTPMs

+ vTPM as standalone component
+ Association deferred to hypervisor
- Additions to hypervisor or involve yet another privileged domain to handle additions
- Cloud functions pushed to hypervisor

vTPM as part of VM abstraction

+ Reduces TCB of vTPM to hypervisor
+ Intuitively fewer possibilities for dynamic modifications
- Aggregation
- vTPMs are controlled by VM and run at hypervisor level

Secure Execution Environment

+ vTPM TCB (sort of) independent from VS
+ Faster attestation infrastructure
- VS still manages connections
- VS info has to be propagated into vTPM

Hardware assisted vTPM

+ Set up VM and hardware manages virtual RoT
+ Hardware assisted vTPM’s
- Significant changes
- TPM 2.0 spec supports some use-cases but no full support is currently possible
Conclusion

Several issues with using virtual TPM as root of trust, association is one of them

vTPM can currently be used against a verifier

Architectural support for virtual TPM might be a trustable solution
Summary of Contributions

Highlight the importance of VM-vTPM association with Goldeneye which uses a vTPM against a verifier

Formal framework and model of virtualization systems with hardware roots of trust

We provide an intuitive link between the system model and classical reasoning

We show how related work may fall victim to a Goldeneye attack and discuss solutions
Impact

Scope for TCG Virtualized Platform WG

New version of Virtualized Trusted Platform Architecture Specification

ISO 27070 Security requirements for virtual Roots of Trust
Thank You

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