Defining the Cloud Battlefield

Supporting Security Assessments by Cloud Customers

Sören Bleikertz [1] Toni Mastelić [2] Sebastian Pape [3]
Wolter Pieters [4] Trajce Dimkov [5]

[1]IBM Research - Zurich

[2]Vienna University of Technology

[3]TU Dortmund

[4]TU Delft / University of Twente

[5]Deloitte LLP

IEEE International Conference on Cloud Engineering 2013
(IC2E)

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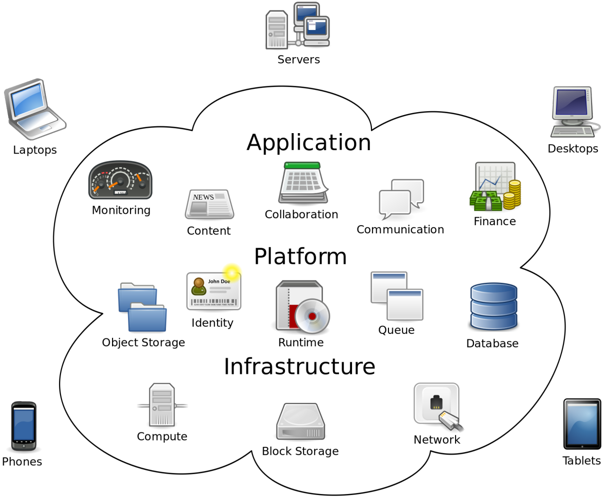
    - Constructing What-if Attack Scenarios
5. Conclusions and Future Work

Introduction
Background: Cloud Computing



Cloud Computing

[wikipedia]

Introduction

Background: Security Concerns in Cloud Computing

- Security is a major concern [Mell and Grance, 2009]
- Analysis of risks and threats
  [Cloud Security Alliance, 2010], [ENISA, 2009]

  ⇒ insider attacks and malicious insiders are a major technical risk
- Risk amplified due disappearance of physical boundaries
  [Hay et al., 2011], [Pieters, 2011]
- Variety of parties involved in a cloud service

  ⇒ cloud customers face difficulties in assessing risks and threats

Introduction

Background: Sample Threats in Cloud Computing

- Malicious cloud administrator attacks virtual machine [Rocha and Correia, 2011]
- Malicious cloud customer attacks other customers who share physical resources [Ristenpart et al., 2009]
- Honest fault of a cloud administrator
  ⇒ outage of Amazon EC2 in 2011 [Amazon Web Services, 2011]
- Honest fault of cloud customers [Bugiel et al., 2011]:
  - SSH public key for administrator account in image
  - private SSH keys, Amazon credentials in image

Introduction

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Samples cover only:

- Two entities: Cloud administrator and customer
- Two characteristics of attacker: honest faults and malicious

Introduction

Research goal: Supporting Security Assessment of Infrastructure Clouds

Aim:

- More fine-grained trust and attacker models
- Systematic specification of parties / capabilities / motivations

→ obtain a complete picture

→ support cloud customer's risk and threat assessments

- Model for cloud customers

→ understandability and usability are important

→ informal model is more accessible to this audience.

Challenge:

- Appropriate level of abstraction
- Combination of expressiveness and understandability

Introduction
Framework Overview

In summary, our framework combines

- System model of infrastructure clouds
  - entities
  - system components
- Security model
  - security objectives of cloud customers
  - attacker characteristics and motivation
  - threats

Introduction

Methodology: Designing an IaaS Threat Model

- Focus on infrastructure clouds (IaaS)
  - partly covers higher layers
  - needed for analysis of higher layers

- Design system model
- Design security model
- Identify and analyse attack scenarios
- Evaluation by mapping existing attacks to model
- Several iterations

- System. analysis by HAZOP approach [Winther et al., 2001]
  1. Identifying known attacks and map them to the model
  2. Analyze remaining combinations of entities, attacker, threats

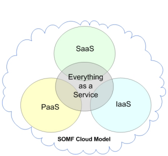
     → reveal possible unknown attacks

System Model

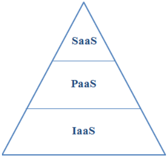
Background Cloud Computing

- Different abstraction layers: *IaaS*, *PaaS*, *SaaS*
- Focus on IaaS
  - ⇐ generic threat model too hard for all layers
  - increasing diversion → SaaS
    - c.f. Google GMail vs. Salesforce CRM
    - ⇒ application-specific attack models
- Existing models not suitable

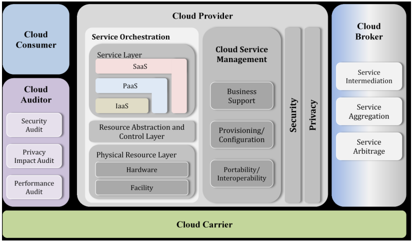
⇒ New cloud system model on IaaS layer consisting of entities and components.



SOMF Model



Cloud Pyramid



NIST Cloud Model

System Model

Entities

Chosen entities for the system model:

Provider manages and operates a cloud infrastructure

Manufacturer produces hardware resources used by the *provider*

Developer produce software used by the *provider*

Customer user of the cloud service provided by the *provider*

Third-party not directly involved in IaaS service,
represents user on higher layers of the cloud service
(e.g., SaaS)

System Model
Components

Each entity has access to one or more components:

Administration service, **logical access** to the cloud infrastructure

Technical Support service, **physical access** to the cloud infrastr.

Hardware e.g. hard-disk, processor, produced by a *manufacturer*, part of a cloud data center.

Software e.g. hypervisor, cloud management software produced by a *developer*, part of a cloud infrastructure.

Data information stored on hardware or being transmitted.

Appliance executable piece of software deployed by a *customer*,
includes higher layers of a cloud service,
black box completely controlled by a *customer*.
non running appliances considered as *data*

Usage represents usage by *third-party*,
logical access of an appliance

System Model

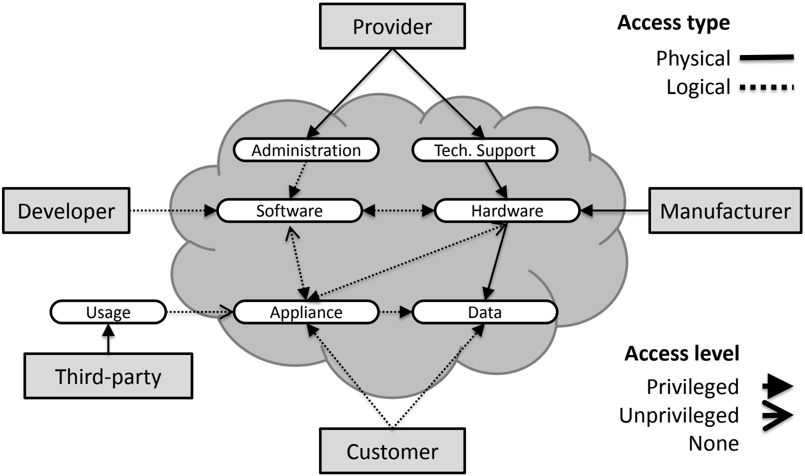


Figure: System model with relations between entities and components.

System Model

Access Type / Periods

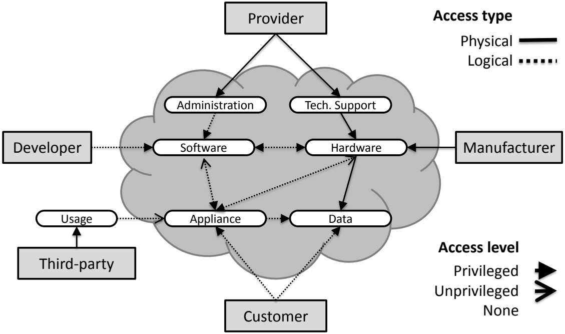


Figure: System model with relations between entities and components.

Access attributes

- direction
- transitivity

Access Type

- physically
- logically

Access Periods

- One-time
- Periodic
- Permanent

System Model

Access Level

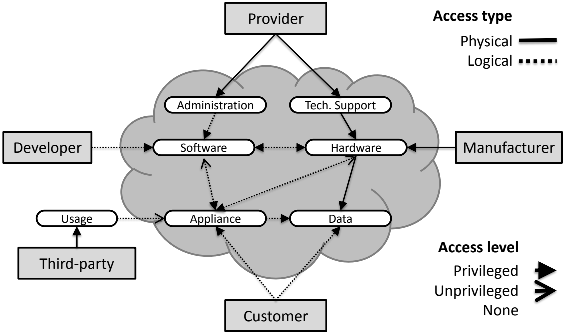


Figure: System model with relations between entities and components.

Access Level

levels:

- privileged
- unprivileged
- none

between:

- entity/comp. (priv.)
- comp./comp.

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Security Model

Security Objectives of Cloud Customers

- Security objectives from a cloud customer's point of view
- Primary concern: exposure of sensitive data
- Focus on *(CIA)*
  - confidentiality
  - integrity
  - availability
- with regard to
  - computing
  - storage
  - network resources

Security Model

Security Objectives of Cloud Customers

Confidentiality of:

- *S1* executed appliances
- *S2* stored data
- *S3* transmitted data and appliances

Integrity of:

- *S4* executed appliances (comp. resources)
- *S5* stored data
- *S6* transmitted data and appliances
- *S7* software: hypervisor & management software

Integrity of: (cont.)

- *S8* hardware

Availability of:

- *S9* appliances: for customers & 3rd parties
- *S10* data: for customers and appliances
- *S11* software: mgmt. infrastructure & hypervisor
- *S12* hardware (analog to software)

Security Model

Attacker Model: Goals and Skills

- Goals
  - what a party wants to achieve
  - may use utility functions, with input
    - damage caused
    - expected gain
    - costs
    - risks associated
- Skills
  - the ability to realize these goals
  - determine outcome when parties have conflicting goals
  - may include a notion of available resources

Security Model

Attacker Model: Archetypes

Archetypes combine goals and skills

malicious (intentionally contribute to an attack): increases risk and associated damage to others for its own gain

ostrich (knowingly contribute to an attack): does not intend to increase risk for others, but fails to take action upon being informed about this (lazy)

charlatan (failing to acquire essential knowledge about contributing to an attack): increases risk for others, could/should have known (sloppy)

stepping stone (unknowingly contribute to an attack): increases risk for others, but could not have known (sloppy)

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- malicious and ostrich archetypes are driven by goals
  - ⇒ skill level determines the success of reaching such goals
- charlatan and stepping stone archetypes have low skills
  - ⇒ goal of providing a secure cloud service unsuccessful

Security Model

Attacker Model: Archetypes

defender (actively tries to prevent an attack): entity reduces risk for others

Motivation for a defender:

reputationalist (tries to improve utility of others to maintain reputation and thereby its own utility)

altruist (tries to improve the utility of others without necessarily benefiting itself)

- Archetypes applied on entities
- Components inherit the archetypes from their entities
- Archetype inherited represents a best possible archetype
  - e.g., *provider* can be a *charlatan*, but *administration* can be worse, i.e. *malicious*.

Security Model
Threat Model

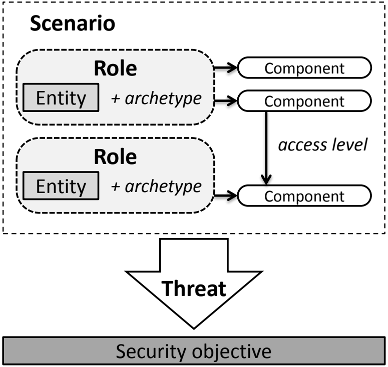

Figure: Deriving a threat from a role based scenario and security objective.

- Define a scenario by using a system model and archetypes
- Combine with security objective

→ Analyze a *threat*

⇒ A threat signals a particular scenario may violate a particular security objective through an attack

- Likelihood of a threat is influenced by attacker's
  - access levels
  - characteristics (including skills and goals)

Model Applications

Evaluation and Purpose

Evaluation:

- Assembled security threats from
  - Cloud Security Alliance [Brunette, 2010]
  - ENISA [Catteddu and Hogben, 2009]
  - Deloitte Cloud Risk Map [Deloitte, 2012]
- developed attack scenarios using subsets from our model

Practical purpose of model:

- Explain success of existing attacks and possible mitigations
- Produce a systematic set of threats
  - → input in developing a security assessment for a cloud solution
- Analyze behavior and motivation of entities
  - → insights into causes of threats
  - → cost-benefit assessment
- Define possible attack scenarios by presenting what-if scenarios in a consistent language

Applying the Model to Practical Attacks

Malicious Administrator Attacks - Scenario Description

- Several known attacks
- Oberheide et. al. [Oberheide et al., 2008]
  - attack on VMWare or Xen
  - administrator targets live migration of virtual machines
  - man-in-the-middle attacks during the migration
  - change of memory data or injection of an SSH key
- Rocha and Correia [Rocha and Correia, 2011]
  - administrator has access on the hypervisor
  - administrator has no access on the virtual machine itself
  - administrator uses memory dumps to derive clear text passwords or cryptographic keys

Applying the Model to Practical Attacks

Malicious Administrator Attacks - Model Application

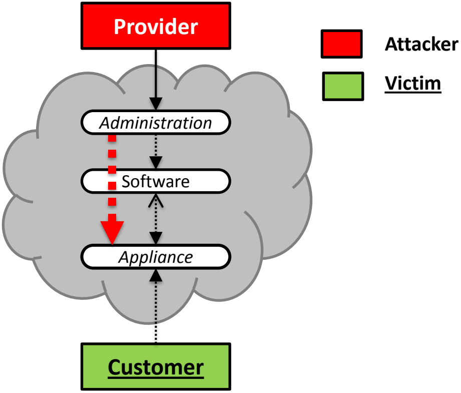

Figure: Malicious administration manipulating an appliance.

- *malicious administrator*
- provider itself may be *malicious* or: *ostrich* to *stepping stone*
- confidentiality and integrity of running *appliance* is violated
- corrupt the *appliance's* template when it is stored or transmitted over the network
- security objectives regarding availability concerned
- *administration* has permanent/periodic access

Applying the Model to Practical Attacks

Malicious Administrator Attacks - Mitigation and Assessment

- differences between possible archetypes of the provider
- no functional
  - *charlatan provider* hires a *malicious administrator*
  - *charlatan provider* fails to implement proper handling of security vulnerability reporting
  - *ostrich* does not perform necessary patch management
- technical mitigation
  - Trusted hypervisors [Garfinkel et al., 2003, Zhang et al., 2011]
  - Access control approaches [Bleikertz et al., 2012]
  - Fully homomorphic encryption [Gentry, 2009]
    still practically infeasible [Van Dijk and Juels, 2010]
  - A two-person administration [Potter et al., 2009]

Applying the Model to Practical Attacks

App Store Scenario - Model Application

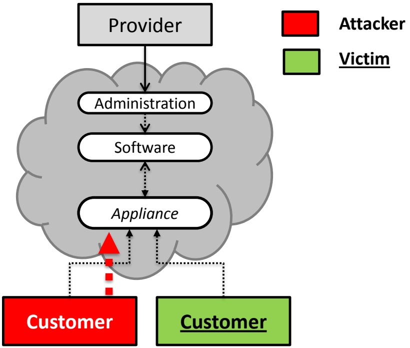

Figure: Attacking other customers through appliances.

- Relevant entities: *provider*, two instances of *customers*
- Two *customers* attack each other at appliance level
- Two scenarios
- leak of confidential information
  - ⇒ availability
  - ⇒ integrity of computations and stored data
  - ⇒ conf. of computations
- *provider* = app store owner
- *provider*: *ostrich*, *charlatan*, *stepping stone* or *defender*

Applying the Model to Practical Attacks

App Store Scenario - Mitigation and Assessment

- Amazon changed from *stepping stone* to *defender* (reputationalist)
- Requires scanning and cleaning of infected/malicious images [Balduzzi et al., 2012]
- Alternatively: pre-emptive image management system that provides a secured access to images [Wei et al., 2009]
- *defender provider* could patch VM images [Zhou et al., 2010]

Applying the Model to Practical Attacks

Side-channel Attacks - Model Application

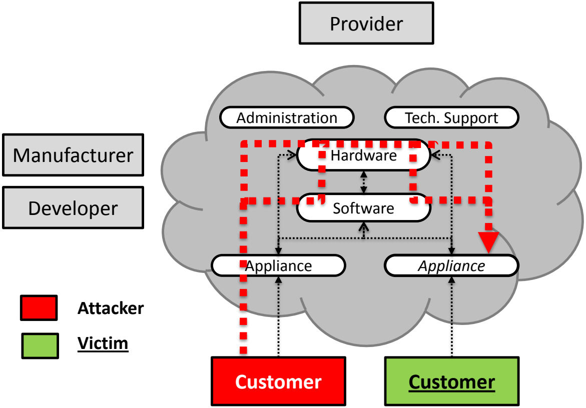

Figure: Attacking other customers through side-channels in hardware and/or software.

Applying the Model to Practical Attacks

Virtual Machine Escapes - Model Application

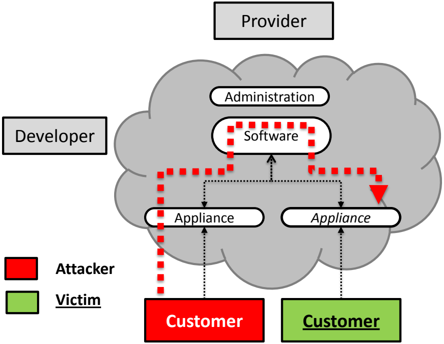

Figure: Attacking customer escapes appliance's environment to attack other customers.

- involved entities
  - attacking and victim *customer*
  - *ostrich* to *stepping stone* or defender cloud *provider*
  - *ostrich* to *stepping stone* or defender software *developer*.
- confidentiality and integrity of the running *appliance* is affected
- integrity of stored or transmitted *appliance*

Applying the Model to Practical Attacks

Constructing What-if Attack Scenarios

- Model also useful for constructing “what-if” scenarios
  - combine multiple entities of our model with attacker roles
  - change an attacker’s characteristic
  - structured assessment of infrastructure cloud security
  - may lead to new attacks

Applying the Model to Practical Attacks

What-if Scenarios: Large Scale VM Escape Attacks

- VM escape attack
- Malicious *customer* + *ostrich*/*charlatan developer*
- Insecure cloud management *software*
- Cloud *provider* and *customers* at large can be attacked
- Injection of management commands into the insecure management *software*
  - ⇒ attacker can terminate appliances
  - ⇒ attacker can consume resources from the *provider* for free
- Additionally: *manufacturer* is *ostrich* or *charlatan*

⇒ hardware could be damaged

Applying the Model to Practical Attacks

What-if Scenarios: Insecure Cloud Management Software / Collusion Attacks in Cloud-of-Clouds

- Insecure Cloud Management Software may lead to the same consequences as VM Escape Attacks
- Cloud-of-Clouds systems aggregate multiple clouds
  - → tolerate byzantine faults of single clouds
  - operated by different organizations
  - ⇒ *administration* and *technical support* of the *providers* do not collude
  - may use the same *software* or *hardware* provided by *malicious/ostrich/charlatan developers* or *manufacturers*
  - ⇒ diminish the security advantages of cloud-of-clouds systems

Applying the Model to Practical Attacks

What-if Scenarios: Hardware Trojans

- [Skorobogatov and Woods, 2012] claim to have discovered hardware trojan
- Not seen in cloud computing, yet
- *Manufacturer* also becomes a *customer* in public clouds that use its *hardware*

→ Malicious *manufacturer* has one-time access to the hardware

→ *Customer* has permanent access to his *appliance*

- May change the way hardware works
- Threats: availability and integrity for
  - other *appliances*
  - the hypervisor and management software

Conclusions and Future Work

- We proposed a cloud security threat model that combines
  - Comprehensive system model of infrastructure clouds
  - Security model focusing on cloud customer security objectives
  - Threat model with characteristics and motivations of attackers
- We used our model to
  - systematic categorization
  - analysis of existing attacks
  - construction of "what-if" attack scenarios
- Customers can apply the approach to competing cloud providers
  - Requires sufficient data about the architecture or Trusted Third Party [Probst et al., 2012].

Conclusions and Future Work

- Model forced a structured approach in describing existing attacks
- Model is well-suited for attacks involving technical infrastructure and behavior of entities
- Threats involving governance and compliance, or threats to security monitoring, cannot be easily expressed
- By considering entities not directly involved in an attack, amplification or reduction of threats by these entities can be made visible

Future Work

- Formalization of our model
  - process calculi for the system model
  - utility functions for the attacker goals
- Extend scope of our model
  - upper abstraction layers in cloud computing, e.g. PaaS
  - consider non-technical security threats such as legal or compliance ones
- Systematic categorization and analysis of protection mechanisms

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