Methodology to Obtain the Security Controls in Multi-cloud Applications

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Abstract: What controls should be used to ensure adequate security level during operation is a non-trivial subject in complex software systems and applications. The problem becomes even more challenging when the application uses multiple cloud services which security measures are beyond the control of the application provider. In this paper, a methodology that enables the identification of the best security controls for multi-cloud applications whose components are deployed in heterogeneous clouds is presented. The methodology is based on application decomposition and modelling of threats over the components, followed by the analysis of the risks together with the capture of cloud business and security requirements. The methodology has been applied in the MUSA EU H2020 project use cases as the first step for building up the multi-cloud applications' security-aware Service Level Agreements (SLA). The identified security controls will be included in the applications' SLAs for their monitoring and fulfilment assurance at operation.

1 INTRODUCTION

Multi-cloud approaches that promote the simultaneous usage of multiple cloud services are emerging as a solution to optimise availability, performance and cost of the applications (Ferry et al., 2013).

Different approaches for multi-cloud have been proposed in the literatures (Bernstein et al., 2009), (Celesti et al., 2010) and (Singhal et al., 2013). Recently, (Bohli et al., 2013) presented a four-type classification of the security-enhancing architectural approaches for multi-cloud applications: replication of application tasks, partition of system into tiers, partition of logic into fragments, and partition of data into fragments. In this paper, only the last three types are considered i.e., those where the application is partitioned into components, be they application business logic or data, deployed in different clouds.

This paper presents the methodology for the selection of desired security controls over multi-cloud applications. The methodology is applicable to any of the partition-based multi-cloud approaches considered and enables the identification of the application components' risks and the derivation of the appropriate security controls to apply to both application components and the cloud services exploited by such components. These security controls will be used to build the Service Level Agreement (SLA) that describes the Service Level Objective (SLO) clauses promised to the multi-cloud application customers. The SLA that includes information of guaranteed security controls is the basis for the assessment of adequate performance of security behaviour during operation.

The paper is structured as follows. Section 2 introduces the security challenges in multi-cloud applications, Section 3 discusses existing approaches for threat modelling as the basis for the security control identification and Section 4 introduces the security control identification methodology while Section 5 describes the methodology applicability and results of its adoption in a particular case study of MUSA project. Finally, Section 6 concludes the paper explaining future work.

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2 MULTI-CLOUD APPLICATIONS SECURITY

The term Multi-Cloud denotes the usage of multiple, independent clouds by a client or a service, unlike Cloud Federations that are achieved when a set of cloud providers voluntarily interconnect their infrastructures to allow sharing of resources among each other ((Global Inter-cloud Technology Forum, 2010), (Nikolay and Buyya, 2012)). Even if, at state of the art, few concrete multi-cloud solutions exists, the topic is considered extremely relevant: the need for multi-cloud solution is well demonstrated by the number of research projects that are proposing solutions and techniques to address the multi-cloud approach, like OPTIMIS, mOSAIC, MODAClouds, PaaSAge, Cloud4SOA ((Petcu et al. 2011), (Ferrer et al. 2012)).

Multi-cloud approaches are debatable, with respect to security: some authors propose multi-cloud approach as a way to improve the level of security for customers, other authors suggest that distributing applications among multiple Cloud Service Providers (CSPs) increase the number of security issues, obtaining as a result a lower level of security.

(Alzain et al., 2014) and (Bernstein and Vij, 2010) offers simple surveys of solutions that try to improve the security using multi-cloud techniques. In concrete, the main results are available for storage services. For example, (Yan et al., 2012) and (Oliveira et al., 2010) propose techniques to distribute a file over multiple providers or untrusted networks, granting higher confidentiality and the integrity of data. It is worth noticing that all the papers that sustain the higher security of the multi-cloud approach focus on increasing one or more specific security property offered to the customers.

(Bohli et al., 2013) and (Singhal et al., 2013) face the security in multi-cloud applications in a different perspective: they analyse different multi-cloud solutions and try to make a security assessment of the overall application behaviour, outlining the new security issues introduced by the multi-cloud approach. While the security assessment approach is very interesting, both papers deal with a very high-level description of the solution and do not offer a clear solution to make an assessment for a real multi-cloud application.

At best of author's knowledge there are no concrete techniques that try to address the issue of developing multi-cloud application taking into consideration the user security requirements from the early development stages.

3 THREAT MODELLING TECHNIQUES

In order to address systematically security issues in multi-cloud applications, it is proposed in this paper according to security best practices (Myagmar, 2005), to perform a security assessment from the early development stages: multi-cloud application design will include the definition of a threat model, which is a structured representation of all the information that affects the security of an application. Thanks to the integrated threat model, it will be possible to perform a systematic risk analysis of the multi-cloud application; identifying the security requirements requested to CSPs.

At state of the art, there are at least two general approaches to threat modelling: attack-based and software-based. Attack-based approaches build a threat model starting from the attacker point of view and aiming at identifying the possible attacks to the target software. Examples of such an approach are threat models based on attack trees (Saini et al., 2008). Software-based approaches focus on the architecture of the software to be secured and aim at classifying the possible risks in order to rank their importance and address them according to different priority levels (Sodiya et al., 2007).

In this paper, the multi-cloud application is mainly composed of web applications (see further sections), and so the approaches suggested by the OWASP project (OWASP, 2015) was adopted as it collects tools devoted to web security. The threat modelling technique adopted is STRIDE methodology, proposed by Microsoft and largely adopted in the context of web applications (Sodiya et al., 2007). According to such approach, threats are classified in 6 categories: *Spoofing*, *Tampering with Data*, *Repudiation*, *Information Disclosure*, *Denial of Service* and *Elevation of Privilege*.

4 PROPOSED METHODOLOGY

In the proposed methodology, the security controls address not only the threats identified during the risk assessment process, but also the business requirements that can be tackled by security controls. For example, in cloud computing, data location is a variable where the service consumer has little influence; nevertheless, applications storing personal data must have very clear control on the location where this data is stored. These types of requirements are identified in a business requirements capture phase and addressed by security controls, which otherwise would be skipped by traditional threat modelling techniques, which focus on security attacks.

The proposed methodology is composed of five steps, namely application decomposition, threat identification and risk assessment, business requirements capture, cloud security requirements identification and selection of security controls. The threat identification and business requirements capture steps may be performed in parallel as they are inputs for the cloud security requirements identification step. These five steps constitute a process of application security analysis which is very essential in the identification of threats, determination of mitigating measures and implementation of security controls in multi-cloud applications. The sequence of the proposed methodology is shown in Figure 1 and thereafter the methodology is explained in detail.

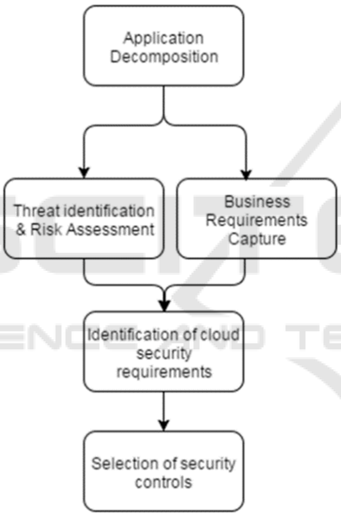

Application Decomposition
Threat identification & Risk Assessment
Business Requirements Capture
Identification of cloud security requirements
Selection of security controls

Figure 1: Proposed methodology for obtaining security controls.

4.1 Application Decomposition

The first step of the methodology is application decomposition. It involves breaking down an application into the different components which make up the application. It provides an insight on the operation and relationship of the application with external entities and helps to identify potential threat targets. It consists of three stages, namely identification of assets, identification of entry points and identification of trust levels. Asset identification is the identification of application components that are prone to attack i.e., the components likely to be attacked. Identification of entry points involves identifying the interfaces through which connection may be made to the application i.e., the points of access to the application such as HTTP ports etc. The identification of trust levels involves identifying the different levels of access rights that would be granted to external entities by the application.

4.2 Threat Identification and Risk Assessment

The second step of the methodology is threat identification and risk assessment. Threat identification is the determination of threats per application component and Risk assessment is the evaluation of the risk associated with the identified threats. STRIDE (a threat categorization methodology) is used identify the threats associated with the application components and Risk assessment is then performed so as to evaluate the potential risks associated with the identified threats. The risk can be estimated using a value-based risk model like DREAD (OWASP, 2015) or quantitative risk model i.e., where Risk is computed as the product of likelihood and impact. (Risk = likelihood x impact).

4.3 Business Requirements Capture

The third step of the methodology is business requirements capture. This is performed in order to identify the cloud compliance requirements for example, for data governance. In multi-cloud applications, certain requirements have to be met in order to fulfil data governance particularly as it concerns storage, back-up, transfer and protection of data. These sets of requirements constitute the business requirements capture for the multi-cloud application. For instance, for data location and storage, certain data governance laws exist which a data controller (*the determiner of use of personal data*) must comply with before processing personal data. Therefore, the business requirements capture must be made in order to identify these requirements and also to ensure that the cloud components of the multi-cloud application comply with the relevant data law requirements.

4.4 Cloud Security Requirements Identification

The fourth step of this methodology is cloud security requirements identification. Cloud security requirements refer to the security and privacy requirements for cloud services. These requirements are derived from cloud computing industrial standards and relevant data protection laws. It serves as a guide for assessing the level of security and identifying the security requirements needed to protect the cloud environment. Cloud security requirements further supplements the threats and business capture requirements identified in the previous steps. It helps to identify the security requirements needed to mitigate identified risks in the second step of the methodology and also other security requirements needed to fulfil legal and business requirements.

4.5 Selection of Controls

The last step of the methodology deals with the identification of the countermeasures needed to satisfy the security requirements. Countermeasures are represented using standard security control frameworks ((NIST, 2014), (CSA, 2011)). Security controls are implemented to ensure confidentiality, integrity and availability and to meet a set of defined security requirements (NIST, 2014).

Security Control Frameworks collects and organize security controls in order to offer guidelines to building secure systems in a standard way: thanks to the standard list of controls it is possible to assess the security of a system and compare it with requirements, verifying how many and in which way controls are concretely implemented. At state of the art, controls are adopted by certification authorities and/or third parties that by a (human–driven) audit verify compliance with security requirements and eventually regulations.

In order to apply the proposed approach in the cloud environment and for specific services, instead that respect to the overall CSPs' infrastructure, recently such controls are embedded into Security SLA in order to grant the level of security offered by each service (Casola, 2015b).

In the proposed methodology, the security control of the NIST framework is classified with respect to category of threats, type of components and security requirement, in order to identify the set of controls needed for each component of the multi-cloud application.

5 APPLICATION OF THE METHODOLOGY IN A CASE STUDY

The methodology explained in the foregoing section is applied in a case study in order to identify the threats and determine the appropriate security control measures. The case study is Tampere Smart Mobility (TSM). TSM is a smart mobility multi-cloud application which enables and supports an energy efficient and smart mobility of citizens of Tampere, Finland. It provides users with customized journey recommendations from which they can make their choice. To achieve this, the TSM stores their personal data, such as name, age and mobility habits on the cloud. Therefore, adequate security controls is needed in the TSM application to protect the personal data of the users. The next section shows how the methodology is applied in this case study.

5.1 Application Decomposition

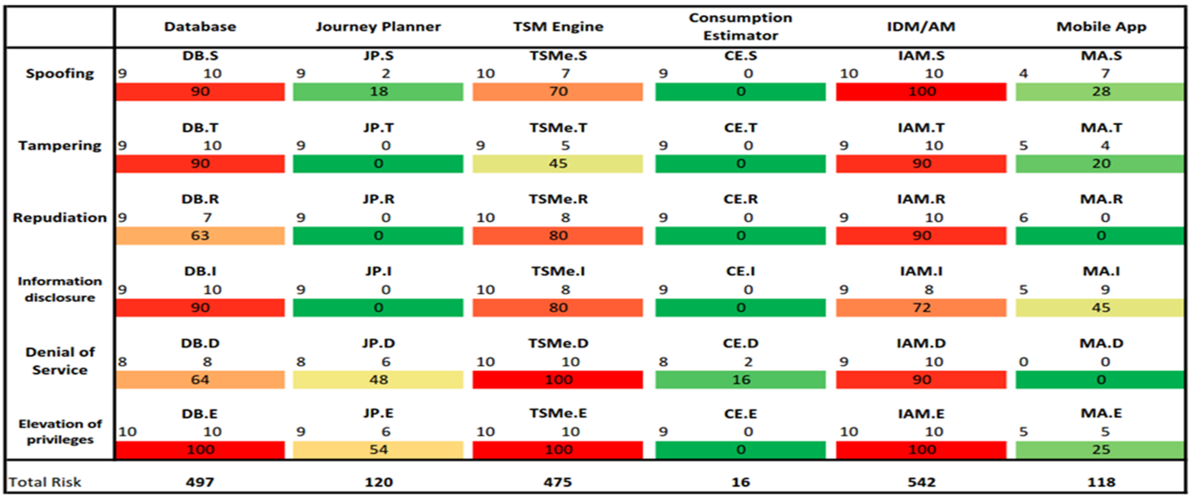
The TSM application is carefully analyzed in order to identify the assets, entry points and trust levels. On the decomposing the TSM application, six assets i.e., the threats targets were identified, namely mobile app, database, TSM engine, Journey planner, Consumption estimator and the Identity manager/Access manager. All the assets apart from the mobile app would be deployed in a multi-cloud layout. The TSM application entry points are mobile user interface, HTTP, web server and HTTP port. The trust levels are: administrator (back-end application manager), end user (citizens) and TSM components (TSM assets).

5.2 Threat Identification and Risk Assessment

In the identification of threats in the TSM application, the STRIDE categorization methodology was used. The STRIDE methodology was applied to all the TSM application assets identified in the previous step **(5.1)**. The likelihood and impact of each threat on each asset was estimated, thus resulting in the risk assessment of the TSM application. A quantitative approach was used to evaluate the risk associated with each asset i.e., on a scale of (0-10), numerical values were estimated for the **likelihood** and **impact** of each threat on each component. With these parameters the computed risk ranges from 0 (no risk) to 100 (high risk).

Table 1 shows the result of step **(5.2)** DB.S represents Database spoofing threat; JP.T represents Journey planner tampering threat and so on.

Table 1: TSM application threat identification and risk assessment.



	Database	Journey Planner	TSM Engine	Consumption Estimator	IDM/AM	Mobile App
Spoofing	DB.S 9 10 90	JP.S 9 2 18	TSMe.S 10 7 70	CE.S 9 0 0	IAM.S 10 10 100	MA.S 4 7 28
Tampering	DB.T 9 10 90	JP.T 9 0 0	TSMe.T 9 5 45	CE.T 9 0 0	IAM.T 9 10 90	MA.T 5 4 20
Repudiation	DB.R 9 7 63	JP.R 9 0 0	TSMe.R 10 8 80	CE.R 9 0 0	IAM.R 9 10 90	MA.R 6 0 0
Information disclosure	DB.I 9 10 90	JP.I 9 0 0	TSMe.I 10 8 80	CE.I 9 0 0	IAM.I 9 8 72	MA.I 5 9 45
Denial of Service	DB.D 8 8 64	JP.D 8 6 48	TSMe.D 10 10 100	CE.D 8 2 16	IAM.D 9 10 90	MA.D 0 0 0
Elevation of privileges	DB.E 10 10 100	JP.E 9 6 54	TSMe.E 10 10 100	CE.E 9 0 0	IAM.E 10 10 100	MA.E 5 5 25
Total Risk	497	120	475	16	542	118

5.3 Business Requirements Capture

In identifying the cloud compliance requirements for data governance in the TSM application, the Finnish Personal Data Act (523/1999) was applied. This is because Tampere University of Technology (TUT) (*the data controller*) is established in Finland. The Act specifies the requirements and guidelines aimed at protecting the rights and privacy of users in the processing of their personal data. The identified business requirements are duties of data controller and data owner, data storage location & transfer of data and data security.

In summary, this act requires that the collected data must be stored within the European Union (EU). In case it is transferred out of EU, the destination must be within the list of authorized countries. The data controller must provide data privacy protection and inform the users about the location of their data, so data awareness is required.

5.4 Cloud Security Requirements Identification

In order to identify the cloud security requirements for the TSM application, the SINTEF cloud security requirements catalog (Bernsmed et al., 2015) was used. Based on the results of the risk assessment (**5.2**) and the business requirements capture (**5.3**), a security requirement matrix was generated. It specifies the relevant security requirements per component of the TSM application. A security requirement is needed if it can mitigate the risk of the threat computed in the step two of the methodology or if it can address a business requirement, captured in the step three of the methodology.

5.5 Selection of Controls

According to the Threat analysis performed and the selection of security requirements, the needed specific security controls can now be identified. A set of properties to be respected is identified for each of the threat categories of the STRIDE methodology and for each of the components.

In order to identify the security controls requested to our multi-cloud application, the properties identified above are listed, and the control family which addresses the security issue and the specific controls that must be implemented to grant the correct level of security is also listed.

6 CONCLUSIONS

Application security assurance in multi-cloud environments is a challenging topic due to the lack of standards and widely adopted best practices. The proper selection of security controls over multi-cloud application components and the cloud services they use is crucial for an adequate assessment of SLA fulfilment and regulatory compliance. As explained above, this selection depends on the risk profile wanted for the application and the multi-cloud approach adopted.

This paper introduces a methodology for the systematic identification of multi-cloud application threats and risks, as well as the derivation of security controls that can be used to monitor and manage desired security aspects of multi-cloud applications at runtime. The methodology is compatible with SLA-driven continuous security assurance and it will be supported by the MUSA framework tools.

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