

## Review of Trust-based File Sharing in Cloud Computing

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**Abstract**—The recent advances in cloud computing have risen a number of unforeseen security related issues in different aspects of cloud environments. Among these, the problem of guaranteeing secure access to computing resources in the cloud is gathering special attention. In this paper, we address open issues related to trust in cloud environments proposing a new trust model for cloud computing which considers a higher level view cloud resources.

**Keywords**—Cloud Computing; Distributed Computing; Security; Integrity; Confidentiality; Trust and Availability.

### I. INTRODUCTION

The widespread use of Internet connected systems and distributed applications has triggered a revolution towards the adoption of pervasive and ubiquitous cloud computing environments. These environments allow users and clients to purchase computing power according to necessity, elastically adapting to different performance needs while providing higher availability. Several web-based solutions, such as Google Docs and Customer Relationship Management (CRM) [2] applications, now operate in the software as a service model. Much of this flexibility is made possible by virtual computing methods, which can provide adaptive resources and infrastructure in order to support scalable on-demand sales of such applications. Virtual computing is also applied to stand-alone infrastructure as a service solutions, such as Amazon Elastic Cloud Computing (EC2) and Elastic Utility Computing Architecture Linking Your Programs to Useful Systems (Eucalyptus) [2].

As a result, the cloud computing frameworks and environments are able to address different issues in current distributed and ubiquitous computing systems.

The availability of infrastructure as a service and platform as a service environments provided a fundamental base for building cloud computing based applications. It also motivated the research and development of technologies to support new applications. As several large companies in the communications and information technology sector have adopted cloud computing based applications, this approach is becoming a de facto industry standard, being widely adopted by different organizations.

Since the adoption of the cloud computing paradigm by IBM Corporation around the end of 2007, other companies such as Google (Google App Engine), Amazon (Amazon

Web Services (AWS), EC2 (Elastic Compute Cloud) and S3 (Simple Storage Service)), Apple (iCloud) and Microsoft (Azure Services Platform) have progressively embraced it and introduced their own new products based on cloud computing technology [11]. However, cloud computing still poses risks related to data security in its different aspects (integrity, confidentiality and authenticity).

In this paper, we review the main cloud computing architecture patterns and identify the main issues related to security, privacy, trust and availability. In order to address such issues, we present a high level architecture for trust models in cloud computing environments.

This paper is organized as follows. In Section II, we present an overview of cloud computing, presenting a summary of its main features, architectures and deployment models. In Section III, we present related works. In Section IV, we introduce the proposed trust model. Finally, in Section V, we conclude with a summary of our results and directions for new research.

### II. CLOUD COMPUTING

Cloud computing refers to the use, through the Internet, of diverse applications as if they were installed in the user's computer, independently of platform and location. Several formal definitions for cloud computing have been proposed by industry and academia. We adopt the following definition: "Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [14]. This definition includes cloud architectures, security, and deployment strategies.

Cloud computing is being progressively adopted in different business scenarios in order to obtain flexible and reliable computing environments, with several supporting solutions available in the market. Being based on diverse technologies (e.g. virtualization, utility computing, grid computing and service oriented architectures) and constituting a whole new computational paradigm, cloud computing requires high level management routines. Such management activities include: (a) service provider selection; (b) virtualization technology selection; (c) virtual resources allocation; (d) monitoring and auditing in order to guarantee Service Level Agreements (SLA).

Computational trust can be leveraged in order to establish an architecture and a monitoring system encompassing all these needs and still supporting usual activities such as planning, provisioning, scalability and security. Chang et al. [15] present a few challenges related to security, performance and availability in the cloud.

*A. Characteristics of Cloud Computing*

One advantage of cloud computing is the possibility of accessing applications directly from the Internet, with minor requirements of user computing resources. There are other significant advantages and disadvantages [13], as shown in Table I.

In cloud computing environments, the user does not need to know all the structure of the system that he is part of. For instance, the user does not need to be aware of information such as how many servers execute a given tool, hardware and software configurations, scalability measures physical data center location. Being relieved of managerial duties, the user can simply and transparently access the applications and tools necessary for performing his main business activities.

TABLE I. ADVANTAGES AND DISADVANTAGES OF CLOUD COMPUTING

Advantages	Disadvantages
Lower IT infrastructure cost	Requires a constant Network connection
Increased computing power	Dependable of network bandwidth
Unlimited storage capacity	Features might be limited
Improved compatibility between operating Systems	Stored data might not be secure
Easier group collaboration	If the cloud loses your data, you will not have access to your information.
Universal access to documents	

Cloud computing combines a shared and statistical service model. It presents three basic characteristics [1]: a) hardware infrastructure architecture – based on low cost scalable clusters. The computing infrastructure in the cloud is composed of a great number of low cost servers, such as standard X86 server nodes; b) collaborative development of basic services and applications with maximal resource utilization, thus improving traditional software engineering processes. In the traditional computational model, applications become completely dependent on the basic services; c) the redundancy among several low cost servers is guaranteed through software. Since a large number of low cost servers is used, individual node failures cannot be ignored. Therefore, node fault tolerance must be taken into account in the design of software.

*B. Cloud Computing Architecture*

Cloud computing architecture is based on layers. Each layer deals with a particular aspect of making application resources available. Basically there are two main layers: a lower and a higher resource layer. The lower layer comprises the physical infrastructure and is responsible for the virtualization of storage and computational resources. The higher layer provides specific services. These layers may

have their own management and monitoring system, independent of each other, thus improving flexibility, reuse and scalability. Figure 1 presents the cloud computing architectural layers [11].

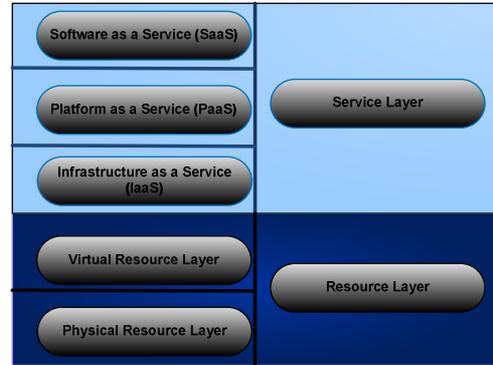


Figure 1. Cloud Computing Architecture [11]

*C. Software as a Service*

Software as a Service (SaaS) provides all the functions of a traditional application, but provides access to specific applications through Internet. The SaaS model reduces concerns with application servers, operating systems, storage, application development, etc. Hence, developers may focus on innovation, and not on infrastructure, leading to faster software systems development.

SaaS systems reduce costs since no software licenses are required to access the applications. Instead, users access services on demand. Since the software is mostly Web based, SaaS allows better integration among the business units of a given organization or even among different software services. Examples of SaaS include [2]: Google Docs and Customer Relationship Management (CRM) services.

*D. Platform as a Service*

Platform as a Service (PaaS) is the middle component of the service layer in the cloud. It offers users software and services that do not require downloads or installations. PaaS provides an infrastructure with a high level of integration in order to implement and test cloud applications. The user does not manage the infrastructure (including network, servers, operating systems and storage), but he controls deployed applications and, possibly, their configurations [4].

PaaS provides an operating system, programming languages and application programming environments. Therefore, it enables more efficient software systems implementation, as it includes tools for development and collaboration among developers. From a business standpoint, PaaS allows users to take advantage of third party services, increasing the use of a support model in which users subscribe to IT services or receive problem resolution instructions through the Web. In such scenarios, the work and the responsibilities of company IT teams can be better managed. Examples of SaaS [2] include: Azure Services Platform (Azure), Force.com, EngineYard and Google App Engine.

E. Infrastructure as a Service

Infrastructure as a Service (IaaS) is the portion of the architecture responsible for providing the infrastructure necessary for PaaS and SaaS. Its main objective is to make resources such as servers, network and storage more readily accessible by including applications and operating systems. Thus, it offers basic infrastructure on-demand services. IaaS has a unique interface for infrastructure management, an Application Programming Interface (API) for interactions with hosts, switches, and routers, and the capability of adding new equipment in a simple and transparent manner. In general, the user does not manage the underlying hardware in the cloud infrastructure, but he controls the operating systems, storage and deployed applications. Eventually he can also select network components such as firewalls.

The term IaaS refers to a computing infrastructure, based on virtualization techniques that can scale dynamically, increasing or reducing resources according to the needs of applications. The main benefit provided by IaaS is the pay-per-use business model [4]. Examples of IaaS [2] include: Amazon Elastic Cloud Computing (EC2) and Elastic Utility Computing Architecture Linking Your Programs To Useful Systems (Eucalyptus).

F. Roles in Cloud Computing

Roles define the responsibilities, access and profile of different users that are part of a cloud computing solution. Figure 2 presents these roles defined in the three service layers [3].

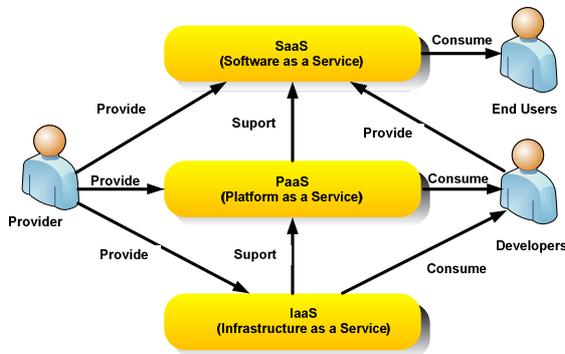


Figura 2. Roles in cloud computing [3].

The provider is responsible for managing, monitoring and guaranteeing the availability of the entire structure of the cloud computing solution. It frees the developer and the final user from such responsibilities while providing services in the three layers of the architecture.

Developers use the resources provided by IaaS and PaaS to provide software services for final users.

This multi-role organization helps to define the actors (people who play the roles) in cloud computing environments. Such actors may play several roles at the same time according to need or interest. Only the provider supports all the service layers.

G. Cloud Computing Deployment

According to the intended access methods and availability of cloud computing environments, there are different models of deployment [4]. Access restriction or permission depends on business processes, the type of information and characteristics of the organization. In some organizations, a more restrict environment may be necessary in order to ensure that only properly authorized users can access and use certain resources of the deployed cloud services. A few deployment models for cloud computing are discussed in this section. They include private cloud, public cloud, community cloud and hybrid cloud, which are briefly analyzed below.

**Private:** In this model, the cloud infrastructure is exclusively used by a specific organization. The cloud may be local or remote, and managed by the company itself or by a third party. There are policies for accessing cloud services. The techniques employed to enforce such private model may be implemented by means of network management, service provider configuration, authorization and authentication technologies or a combination of these.

**Public:** Infrastructure is made available to the public at large and can be accessed by any user that knows the service location. In this model, no access restrictions can be applied and no authorization and authentication techniques can be used.

**Community:** Several organizations may share the cloud services. These services are supported by a specific community with similar interests such as mission, security requirements and policies, or considerations about flexibility. A cloud environment operating according to this model may exist locally or remotely and is normally managed by a commission that represents the community or by a third party.

**Hybrid:** Involves the composition of two or more clouds. These can be private, community or public clouds which are linked by a proprietary or standard technology that provides portability of data and applications among the composing clouds.

III. RELATED WORKS

In this section, we present related works in the fields of security, file systems and trust in the cloud.

A. Security in the Cloud

A number of technologies have been employed in order to provide security for cloud computing environments. The creation and protection of security certificates is usually not enough to ensure the necessary security levels in the cloud. Cryptographic algorithms used with cloud applications usually reduce performance and such reduction must be restricted to acceptable levels [21].

Cloud computing offers users a convenient way of sharing a large quantity of distributed resources belonging to different organizations. On the other hand, the very nature of the cloud computing paradigm makes security aspects quite more complex. Trust is the main concern of consumers and service providers in a cloud computing environment [7]. The

inclusion of totally different local systems and users of quite diverse environments brings special challenges to the security of cloud computing. On one hand, security mechanisms must offer users a high enough level of guarantees. On the other hand, such mechanism must not be so complex as to make it difficult for users to use the system. The openness and computational flexibility of popular commercially available operating systems have been important factors to support the general adoption of cloud computing. Nevertheless, these same factors increase system complexity, reduce the degree of trust and introduce holes that become threats to security [7].

Huan et al. [22] investigate the different security vulnerability assessment methods for cloud environments. Experiments show that more vulnerabilities are detected if vulnerable tools and servers are in the same LAN. In other word, the hackers can find an easier way to get the target information if it is on the same LAN of compromised systems. Experimental results can be used to analyze the risk in third party compute clouds.

Popovic et al. [23] discuss security issues, requirements and challenges that Cloud Service Providers (CSP) face during cloud engineering. Recommended security standards and management models to address these are suggested both for the technical and business community.

### B. Filesystem Security

As the number of devices managed by users is continually increasing, there is a growing necessity of synchronizing several hierarchically distributed file systems using ad-hoc connectivity. Uppoor et al. [6] present a new approach for synchronizing of hierarchically distributed file systems. Their approach resembles the advantages of peer-to-peer synchronization, storing online master replicas of the shared files. The proposed scheme provides data synchronization in a peer-to-peer network, eliminating the costs and bandwidth requirements usually present in cloud computing master-replica approaches.

The work in [9] presents CDRM, a scheme for dynamic distribution of file replicas in a cloud storage cluster. This scheme periodically updates the number and location of file block replicas in the cluster. The number of replicas is updated according to the actual availability of cluster nodes and the expected file availability. The dynamic distribution algorithm for replica placement takes into account the storage and computational capacity of the cluster nodes, as well as the bandwidth of the communication network. An implementation of the proposed scheme using an open source distributed file system named HDFS (Hadoop Distributed File System) is discussed. Experimental measurements point out that the dynamic scheme outperforms existing static file distribution algorithms.

### C. Trust

The concepts of trust, trust models and trust management have been the object of several recent research projects. Trust is recognized as an important aspect for decision-

making in distributed and auto-organized applications [19] [20]. In spite of that, there is no consensus in the literature on the definition of trust and what trust management encompasses. In the computer science literature, Marsh is among the first to study computational trust. Marsh [19] provided a clarification of trust concepts, presented an implementable formalism for trust, and applied a trust model to a distributed artificial intelligence (DAI) system in order to enable agents to make trust-based decisions. Marsh divided trust into three categories: **1. Basic Trust** – This is the level of trust which represents the general trust disposition of agent  $X \in 2^A$  at time  $t$ . **2. General Trust** – Given agents  $x, y \in A$ , the general trust  $T_x(y)^t$  represents the amount of trust that  $x$  has in  $y$  at time  $t$ . **3. Situational Trust** – Given agents  $x, y \in A$ , and a situation  $\alpha$ , the situational trust  $T_x(y, \alpha)^t$  represents the amount of trust that  $x$  has in  $y$  in situation  $\alpha$  at time  $t$ .

Beth et al. [20] also proposed a trust model for distributed networks. They derived trust recommendations from direct trust and gave them formal representations, as well as rules to derive trust relationships and algorithms to compute trust values. Josang et al. [24] describe a trust model where positive and negative feedback about a specific member is accumulated. The model is based on the Bayesian network model, using the beta probability density function to calculate a member's expected future behavior.

Trust is considered to be more than the authorized nature of security relations between human societies, which achieve stable and healthy operation, to a large extent thanks to the trust relationship between the individuals, groups and organizations. Therefore, in a large number of dynamic user-oriented open network environments, the study of the trust relationships between the trust-based security mechanisms to ensure the safe operation of distributed applications has become a fundamental topic. Currently, most scholars have reached a consensus that trust should have three important features [25], which are discussed below.

- 1) Subjectivity (different entities of the same view of things which will be affected by factors such as individual preferences may vary);
- 2) The expected probability (the degree of trust can be extracted and formalized as the estimated likelihood of a given event);
- 3) Relevance (trust is an aspect of things, for specific content).

In recent works on trust, mainly two distinct methods are used for subjective trust reasoning: probabilistic reasoning based on statistical hypothesis testing; and approaches based on fuzzy theory, expert systems and artificial intelligence techniques. However, these methods do not fully reflect the essential nature of trust. Subjective trust, in essence, is based on the belief that it has great uncertainty. In the subjective, objective world, random and fuzzy uncertainties are the two main forms that have become the industry consensus [26]. Thus, the axiomatic methods based on probability theory or

fuzzy set theory do not achieve a comprehensive assessment of trust information.

#### D. Trust in the Cloud

Trust and security have become crucial to guarantee the healthy development of cloud platforms, providing solutions for concerns such as the lack of privacy and protection, the guarantee of security and author rights.

Privacy and security have been shown to be two important obstacles concerning the general adoption of the cloud computing paradigm. In order to solve these problems in the IaaS service layer, a model of trustworthy cloud computing which provides a closed execution environment for the confidential execution of virtual machines was proposed [5]. This work has shown how the problem can be solved using a Trusted Platform Module. The proposed model, called Trusted Cloud Computing Platform (TCCP), is supposed to provide higher levels of reliability, availability and security. In this solution, there is a cluster node that acts as a Trusted Coordinator (TC). Other nodes in the cluster must register with the TC in order to certify and authenticate its key and measurement list. The TC keeps a list of trusted nodes. When a virtual machine is started or a migration takes place, the TC verifies whether the node is trustworthy so that the user of the virtual machine may be sure that the platform remains trustworthy. A key and a signature are used for identifying the node. In the TCCP model, the private certification authority is involved in each transaction together with the TC [5].

Shen et al. [7] presented a method for building a trustworthy cloud computing environment by integrating a Trusted Computing Platform (TCP) to the cloud computing system. The TCP is used to provide authentication, confidentiality and integrity [7]. This scheme displayed positive results for authentication, rule-based access and data protection in the cloud computing environment.

Cloud service providers (CSP) should guarantee the services they offer, without violating users' privacy and confidentiality rights. Li et al. [8] introduced a multi-tenancy trusted computing environment model (MTCEM). This model was designed for the IaaS layer with the goal of ensuring a trustworthy cloud computing environment to users. MTCEM has two hierarchical levels in the transitive trust model that supports separation of concerns between functionality and security. It has 3 identity flows: a) the consumers, who hire the CSP cloud computing services; b) the CSP, that provides the IaaS services; c) the auditor (optional, but recommended), who is responsible for verifying whether the infrastructure provided by the CSP is trustworthy on behalf of users. In MTCEM, the CSP and the users collaborate with each other to build and maintain a trustworthy cloud computing environment.

Zhimin et al. [12] propose a collaborative trust model for firewalls in cloud computing. The model has three advantages: a) it uses different security policies for different domains; b) it considers the transaction contexts, historic

data of entities and their influence in the dynamic measurement of the trust value; and c) the trust model is compatible with the firewall and does not break its local control policies. A model of domain trust is employed. Trust is measured by a trust value that depends on the entity's context and historical behavior, and is not fixed. The cloud is divided in a number of autonomous domains and the trust relations among the nodes is divided in intra and inter-domain trust relations. The intra-domain trust relations are based on transactions operated inside the domain. Each node keeps two tables: a direct trust table and a recommendation list. If a node needs to calculate the trust value of another node, it first checks the direct trust table and uses that value if the value corresponding to the desired node is already available. Otherwise, if this value is not locally available, the requesting node checks the recommendation list in order to determine a node that has a direct trust table that includes the desired node. Then it checks the direct trust table of the recommended node for the trust value of the desired node. The process continues until a trust value for the desired node is found in a direct trust table of some node. The inter-domain trust values are calculated based on the transactions among the inter-domain nodes. The inter-domain trust value is a global value of the nodes direct trust values and the recommended trust value from other domains. Two tables are maintained in the Trust Agents deployed in each domain: form of Inter-domain trust relationships and the weight value table of this domain node.

In [17] a trusted cloud computing platform (TCCP) which enables IaaS providers to offer a closed box execution environment that guarantees confidential execution of guest virtual machines (VMs) is proposed. This system allows a customer to verify whether its computation will run securely, before requesting the service to launch a VM. TCCP assumes that there is a trusted coordinator hosted in a trustworthy external entity. The TCCP guarantees the confidentiality and the integrity of a user's VM, and allows a user to determine up front whether or not the IaaS enforces these properties.

The work [18] evaluates a number of trust models for distributed cloud systems and P2P networks. It also proposes a trustworthy cloud architecture (including trust delegation and reputation systems for cloud resource sites and datacenters) with guaranteed resources including datasets for on-demand services.

#### IV. HIGH LEVEL TRUST MODEL FOR FILE SHARING

According to the review and related research [5] [6] [7] [8] [10] [12] [17], it is necessary to employ a cloud computing trust model to ensure the exchange of files among cloud users in a trustworthy manner. In this section, we introduce a trust model to establish a ranking of trustworthy nodes and enable the secure sharing of files among peers in a public cloud.

We propose a trust model where the selection and trust value evaluation that determines whether a node is

trustworthy can be performed based on node storage space, link and processing capacity. For example, if a given client has access to a storage space in a public cloud, it still has no selection criterion to determine to which cloud node it will send a particular file.

When a node wants to share files with other users, it will select trusted nodes to store this file through the following metrics: processing capacity (the average workload processed by the node, for example, if the node’s processing capacity is 100% utilized, it will take longer to attend any demands), storage capacity and link (better communication links and storage resources imply greater trust values, since they increase the node’s capacity of transmitting and receiving information). The trust value is established based on queries sent to nodes in the cloud, considering the metrics previously described.

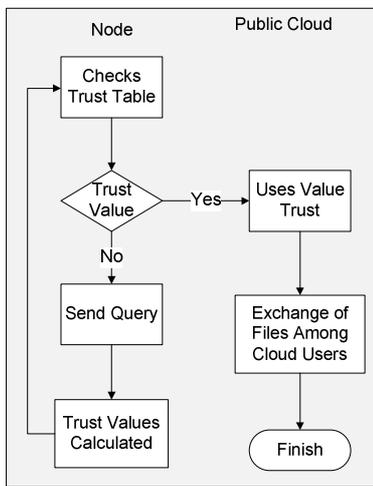


Figure 3. Proposed Trust Model.

Each node maintains two trust tables: direct trust table and the recommended list. a) If a node needs to calculate the trust value of another node, it first checks the direct trust table and uses the trust value if the value for the node exists. If this value is not available yet, then the recommended lists are checked to find a node that has a direct trust relationship with the desired node the direct trust value from this node’s direct trust table is used. If there’s no value attached, then it sends a query to its peers requesting information on their storage space, processing capacity and link. The trust values are calculated based on queries exchanged between nodes.

b) The requesting node will assign a greater trust value to nodes having greater storage capacity and / or processing and better link.

The trust value of a node indicates its suitability for storage and cloud operations. This value is calculated based on the historical interactions of the node, being represented by  $T_{np}$ , for a given node. Its value may range from 0 to 1. As we have previously stated, the value of  $T_{np}$  is calculated from queries exchanged between nodes regarding their overall system capacities. Figure 3 presents a high level view the proposed trust model, where the nodes query their peers to obtain the information needed to build their local trust table.

In this model, a trust rank is established, allowing a node A to determine whether it is possible to trust a node B to perform storage operations in a public cloud. In order to determine the trust value of B, node A first has to obtain basic information on this node. Figure 4 depicts the query exchange process used for gathering the necessary trust information from a node B by a node A.

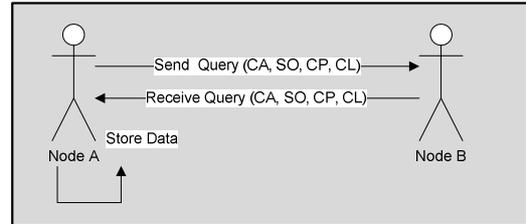


Figure 4. Scenario of Information Request

Node A needs to exchange a file in the cloud and wants know if the node B can be trusted to store and send the file. The protocol Trust Model can be described as follows: In step 1, A sends a query to B regarding its storage capacity, operating system, processing capacity and link. In step 2, B sends a response to he query sent by A, providing the requested information. In step 3, node A evaluates the information received from B and, if the information is consistent, it is stored in A’s local trust table. In general, the trust of node A in node B, in the context of a public cloud NP, can be represented by:

$$T_{a,b}^{np} = V_{np}^b \tag{1}$$

Where  $V_{np}^b$  is the trust value of B in the public cloud NP analyzed by A and  $T_{a,b}^{np}$  represents the trust of A in B, in the public cloud NP. According to the definition of trust,  $V_{np}^b$  equals the queries sent and received (interaction) by A and B in the cloud NP.

The trust information may be stored as individual records of interaction with the respective node, being recorded in a local database that contains information about the behavior of each node in the cloud. Thus, the trust of node A in node B in the cloud NP can be represented by:

$$T_{a,b}^{fnp} = \frac{\sum_{i=1}^j V_{npi}^b}{j}, \text{ for } j > 0 \tag{2}$$

$T_{a,b}^{fnp}$  represents the final trust of A in B in the cloud NP, while j represents the number of interactions / queries between nodes A and B in the cloud NP.

## V. CONCLUSION

We have presented an overview of the cloud computing paradigm, as well as its main features, architectures and deployment models. Moreover, we

identified the main issues related to trust and security in cloud computing environments.

In order to address these issues, we proposed a trust model to ensure reliable exchange of files among cloud users in public clouds. In our model, the trust value of a given node is obtained from a pool of simple parameters related to its suitability for performing storage operations. Nodes with greater trust values are subsequently chosen for further file storage operations.

As a future work, we plan to implement the proposed trust model and analyze node behavior after the ranking of trustworthy nodes is established.

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