Francois D'Ugard



MISSION CRITICAL CLOUD COMPUTING

Feasibility Study and Project Plan

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This project will deliver mission assurance to mission-critical applications in cloud computing systems. We will do so by leveraging the unique capabilities that develop a virtual machine based approach to run applications with good security and reliability in typical cloud computing systems. This project will build upon the previous project's results:

1) A VM management system that dynamically migrate VMs across hosts on an OpenStack-based cloud platform;

2) A P2P overlay network that interconnect the OpenStack VMs based on the IP-over-P2P (IPOP) framework. The project will focus on developing an extension to IPOP that will allow for the communications among the VMs to be routed by an overlay network in an OpenStack-based cloud system.

# Abstract

Virtualization is an increasingly popular approach to manage rising information technology costs and complexity in every sector of the economy. Cloud computing allows organizations of any size to provision infrastructure resources as needed and flexibly scale technology resources to meet changing demands. Cloud providers pool hardware resources and allocate them based on the requests of their users. In order to efficiently allocate these resources providers must aggregate users of different requirements and workloads onto the same physical infrastructure. However, this approach increases the likelihood that a malicious user can collocate a VM alongside a target VM in order to extract information or disrupt its functioning in some way.

We propose a solution that can deliver mission assurance to mission-critical applications in cloud computing systems. We will do so by leveraging the unique capabilities of virtualization technology that and develop a dynamic and distributed approach to run applications with good security and reliability in typical cloud computing systems.

Our approach relies on developing a complete network graph on virtual private network peer to peer connections. With the purpose of reducing the likelihood of a malicious VM locating the mission-critical VM and achieving co-residency with it.

This project will deliver mission assurance to mission-critical applications in cloud computing systems. We will do so by leveraging the unique capabilities that develop a virtual machine based approach to run applications with good security and reliability in typical cloud computing systems. This project will build upon the previous project's results namely a P2P overlay network that interconnect the OpenStack VMs based on the IP-over-P2P (IPOP) framework. The project will focus on developing an extension to IPOP that will allow for the communications among the VMs to be routed by an overlay network in an OpenStack-based cloud system.

This document is an evaluation and analysis of the potential our proposed project. It is based on extensive investigation and research into our problem scope and existing technologies.

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# Introduction

Virtualization is an increasingly popular approach to manage rising information technology costs and complexity in every sector of the economy. Cloud computing allows organizations of any size to provision infrastructure resources as needed and flexibly scale technology resources to meet changing demands. Cloud providers like Amazon, Microsoft, or Rackspace pool hardware resources such as compute, memory, and storage and allocate them based on the provisioning requests of their users and available resources. In order to efficiently and cost effectively allocate these resources providers must necessarily aggregate users of different requirements and workloads onto the same physical infrastructure.

The rising popularity and diffusion of hardware virtualization technology among organizations of every size has led researchers and technology professionals to seriously consider the security of such computer systems. By allocating the virtual machines of different user onto the same infrastructure various security vulnerabilities are created. However many of the unique capabilities of cloud computing can also be used to increase the reliability of the cloud as well as ensure its security and resilience to an attack.

An important quality of virtualization is the ability for users to quickly provision resources as needed. This capability lends itself well to the concept of migration wherein a virtual machine is suspended or shutdown and its resources are reallocated to another physical machine and then restarted or rebooted. This capability can be used to ensure the security of a cloud computing environment.

## Problem Definition

The rising popularity of cloud computing concepts has introduced significant security vulnerabilities into the information technology infrastructure of many organizations. Currently virtualized information technology systems are designed and built to operate on relatively static configurations. Typically cloud services providers fulfill provisioning requests on an as needed basis. In order for cloud computing to remain cost effective infrastructure providers must provision pools of resources, such as CPU, memory, and storage among many different users.

This configuration means that a malicious user can reside alongside a virtual machine that computes mission critical or sensitive data. The sharing of physical infrastructure among virtual machines belonging to different users opens up the possibility of a side-channel attack. A side channel attack occurs when a malicious users is able to locate a target virtual machine and spawn another virtual machine alongside this target. The malicious user is then able to extract information by monitoring the hardware resources shared by both virtual machines.

## Background

Research has been conducted to explore the existing vulnerabilities in current third-party clouds by the sharing of the physical infrastructure among VMs belonging to different users, and analyze the practicality of cross-VMs side-channel attacks in such environments [7].

Moving Target Defense System research has proposed several MTD systems that change the structure of a cloud environment as well as its configuration. These systems operate autonomously and proactively to deny the opportunity for malicious users to exploit the side channel attack vulnerabilities inherent in public clouds.

We propose a proactive dynamic and random moving target defense system that leverages the capabilities of both live and non-live migration. Furthermore we propose a distributed peer to peer virtual private network that maintains the communication network structure of collaborating virtual machines unchanged as frequent migrations take place. Finally in order to increase the resiliency of said network we propose a secondary system the masks the communication between the virtual machines, making the communication patterns of virtual machines difficult to identify and further obfuscating the

## Definitions, Acronyms, and Abbreviations

API - Application Programming Interface: specifies how some software components should interact with each other [16].

Cloud computing: this phrase commonly refers to network-based services, which appear to be provided by real server hardware, and are in fact served up by virtual hardware that is simulated by software running on one or more physical machines [17].

Co-residency: a VM is co-resident with any VM when they are running on the same physical machine, and describes a great security risk when hosting VMs with sensitive data.

IP Address - Internet Protocol address: a numerical label assigned to each device participating in a computer network that uses the Internet Protocol for communication [19].

Hardware virtualization: this term refers to the creation of a virtual machine that acts like a real computer running an operating system [26].

LAN - Local Area Network: a computer network that interconnects computers in a limited area such as a home or a school using network media [21].

Live virtual machine migration: the process of moving a running virtual machine from a physical host to another physical host [6].

MTD - Moving-Target Defense: an approach that has been proposed to better protect important network systems and critical computing infrastructure by dynamically changing properties of their configuration in some way [1].

Non-live virtual machine migration: the process of moving a powered off virtual machine from a physical host to another physical host. After the transfer completes, the migrated virtual machine is restarted [6].

P2P network - Peer-to-peer network: a type of decentralized and distributed network architecture in which individual nodes in the network (called "peers") act as both suppliers and consumers of resources [22].

Private cloud: it is a cloud infrastructure operated solely for a single organization. It can be managed internally or by a third-party, and hosted internally or externally [17].

Public cloud: a cloud is said to be public when the services are rendered over a network that is open for public use, most commonly the Internet [17].

Side-channel attack: any attack based on information gained from the physical implementation of a cryptosystem, rather than brute force or theoretical weaknesses in the algorithms [23].

UML - Unified Modeling language: a standardized, general-purpose modeling language in the field of software engineering. It includes a set of graphic notation techniques to create visual models of object-oriented software-intensive systems [25].

Virtual cluster: a group of VMs configured for a common purpose with associated storage resource, operating system, software environment, communication protocol, and network configuration [12].

VM - Virtual Machine: a software-based emulation of a physical computer [27].

VMM - Virtual Machine Monitor or hypervisor: a piece of computer software, firmware, or hardware that creates and runs virtual machines [20].

Virtual network: a computer network that consists of virtual network links as opposed to physical (wired or wireless) links between connected devices. It is implemented using methods of network virtualization [28].

VPN - Virtual Private Network: A VPN extends a private network across a public network, such as the Internet. It enables a computer to send and receive data across shared or public networks as if it were directly connected to the private network, while benefiting from the functionality, security and management policies of the private network [29].

## Overview of Document

This document is organized into various different sections. Chapter 1 is an introductory section. Section 1.1 defines and describes the problem we will solve. 1.2 provides some background information related to the problem including previous research. Section 1.3 we define and explain various terms and abbreviations found in this document.

Chapter 2 is a study into the feasibility of the proposed system. Section 2.1 describes the current system in place and identifies its current limitations and constraints. Section 2.2 presents the purpose of the system in detail. Section 2.3 is an overview of the user requirements that must be met upon the successful completion of the project. Based on those requirements section 2.4 compares other possible solutions and based on this analysis section 2.5 presents our recommended solution.

Chapter 3 is the project plan. The project plan describes the organization of the project in section 3.1 Also included in section 3.1.1 is the project personnel organization and hard ware and software resources in section 3.1.2. Lastly section 3.2 clearly states that tasks, milestones and deliverables expected upon completion of the project.

Chapter 4 is the appendix. It includes a project schedule in section 4.1. The feasibility matrix in section 4.2 a cost matrix section 4.3 and a diary of meetings in section 4.4

Finally Chapter 5 is a bibliographic reference of any works cited in this document.

# Feasibility Study

The following section analyzes the current system and compares the feasibility of our proposed system considering the current system as well as other alternative solutions. Section 2.1 is a description of the current system, afterward section 2.2 provides an overview of the proposed system. Section 2.3 outlines the user’s requirements of a new system. Section 2.4 outlines alternative solutions to the problem. Section 2.5 finalizes our recommendations for a new system based on the information gathered in the previous sections.

## 2.1. Description of Current System

Currently virtualized information technology systems are designed and built to operate on static configurations. Typically cloud services providers fulfill provisioning requests as requested by their user base. In order for cloud computing to remain cost effective infrastructure providers must provision pools of resources, such as CPU, memory, and storage among many different users. This policy, while cost effective and efficient, opens up the cloud to the possibility of a side channel attack. By mapping the internal structure of the cloud environment a malicious attacker is able to identify a target virtual machine a spawn a malicious virtual machine co-resident to the target. This allows the malicious virtual machine to monitor the shared physical infrastructure and extract sensitive or mission critical data.

Distributed applications require a solution that will guarantee reliable and resilient communication. The current IPOP architecture address this by creating a virtual private network over a peer to peer overlay that allows the virtual machine to communicate using static virtual IP addresses. These ip address should remain constant even when changes in the cloud network, like frequent migrations or failures, take place. However the standard IPOP controllers are not designed to masquerade network traffic among cooperative virtual machines. In particular, current controllers manage link creation and termination in a reactive fashion and do not offer solutions to randomly route packets among the cooperating virtual machines. On the contrary current IPOP controllers are designed with efficiency in mind, creating links of shortest path with no consideration to network latencies and masquerading.

## 2.2. Purpose of New System

This project will deliver mission assurance to mission-critical applications in cloud computing systems. We will do so by leveraging the unique capabilities that develop a virtual machine based approach to run applications with good security and reliability in typical cloud computing systems. This project will build upon the previous project's results:

A P2P overlay network that interconnect the OpenStack VMs based on the IP-over-P2P (IPOP) framework. The project will focus on developing an extension to IPOP that will allow for the communications among the VMs to be routed by an overlay network in an OpenStack-based cloud system.

This project will implement an application-level peer to peer virtual overlay network that interconnects each VM in the mission critical cloud. Additionally this network will be generated randomly at periodic intervals.

## 2.3. High-level Definition of User Requirements

This section describes the requirements that the customer wants to include in the final software product and the constraints on its operation. The client cannot demand features outside the following list and the development team cannot claim completion of the project if it does not satisfy any of the items. The development team reserves the right to consider and negotiate additional features requested by the client.

* The system shall allow the user to list all VM’s with the service enabled
* The system shall allow a user to create a P2P overlay network
* The system shall allow a user to destroy an overlay network
* The system shall allow a user to connect a virtual machine to an existing P2P overlay network
* The system shall allow a user to disconnect a virtual machine from a P2P overlay network
* The system shall expose both the network services via a command line interface.
* The system shall allow a user to specify a configuration file that species all parameters for the overlay network.
* The system shall allow the user to specify a path decay time interval.
* The system shall allow a user to start, stop and restart service at any time.
* The system shall support the execution of applications that use TCP and UDP protocols.
* The system shall not constrain network infrastructure in order to function properly.

## Alternative Solutions

This section provides an overview of existing alternative solutions for the components of our project. The goal of this project is to protect Mission critical virtual machines processing confidential or sensitive data. Approaches that limit the attacker’s ability to successful place a malicious virtual machine co-resident with their target virtual machine or monitor network traffic between co-resident virtual machines will be considered. A brief description of the project problems and background information are included bellow.

1. Communication Network
   1. Centralized host communication server
   2. VPN P2P Overlay Network (IPOP)

### Description of Alternatives

This section provides a high level description of the proposed alternative solutions

Communication Network

1. Centralized host communication server

A predetermined and centralized host list server is known to all virtual machines. Communications flow from the host list server to all other virtual machines within the cloud.

1. VPN P2P Overlay Network

Network information is distributed across the network instead of a central host list server. Communications between virtual machines are routed over a private P2P virtual network. Upon migration link reestablishment with highly collaborative virtual machines takes precedence over other virtual machines.

### Selection Criteria

We consider three criteria for the selection of project solutions they are

* Operational Feasibility
  + This criteria measures the benefit that a solution will have on the daily operations of a cloud administrator. It also measures the effectiveness of a solution and the likelihood of the solution being used effectively.
* Technical Feasibility
  + This criteria describes the maturity of the technology that a proposed solution depends on. It also measures the capability of the team members and the mentor to implement the solution as well as the technology’s effectiveness at solving the problem.
* Economic Feasibility
  + This criteria measures the cost of implementing the solution.

### Analysis of Alternatives

1. Centralized Host Communication Server
   * A centralized communication server introduces a significant, albeit subtle, weakness into a cooperative cloud environment. Once an attacker is co-resident in our cloud, it has the ability to surreptitiously monitor network traffic. Doing so allows the attacker to trivially identify the mission critical virtual machine that resides within our cloud. The mission critical virtual machine is the node that receives the most input and sends the most output traffic. Because this virtual machine is orchestrating the computation functions of all other virtual machines. **Alternatively one can calculate the ratio of incoming to outgoing packets at each node. The closer this ratio is to 1, the higher the likely hood that this virtual machine is the mission critical virtual machine**.
2. VPN P2P Overlay Network
   * A VPN P2P Overlay Network provides similar functionality as the Centralized Host Server without any of the weaknesses. If an attacker is co-resident in our cloud and monitors the network traffic, they will find that it impossible to positively identify the mission critical virtual machine. **Because the network traffic is distributed among all of the friendly nodes in the cloud, each node seems to be sending and receiving approximately the same ratio of communications.** The only alternative is for the attacker is to attempt a system wide parallel attack, iteratively attack each node, or proceed to another attack vector. This increases the likelihood of identifying the attacker virtual machine early and allows the friendly virtual machines time to migrate away from the malicious virtual machine. **Because the system randomly chooses a new path at a certain time interval the average path decay time, path topology, and hop count can be randomized or altered as needed.** This introduces the possibility of implementing honey pot virtual machine or active defense systems. These implementations, however, are left for future work.

## Recommendations

Based on the quantitative study outlined in the previous sections it is the recommendation of this document to proceed with design and implementation of a random and automatic VPN overlay communication network. This approach will best guarantee the security and resilience of a mission critical cloud computing system. The use of a VPN overlay communication network system will reduce the likelihood that a malicious cloud user will be able to accurately identify a mission critical virtual machine. Additionally the system allow any state changed virtual machines to preserve communication and collaboration among their cooperating neighbor nodes.

# Project Plan

This chapter presents the project organization including the personnel assigned to the project, and the mentor and client. We also specify the hardware and software resources required to complete the project. Lastly we identify the tasks, milestones and deliverables of our project and include a timeline of their completion dates.

## 3.1. Project Organization

This section describes the organization of all interested parties participating in the project. This section defines the roles and work domains of all interested parties in order to facilitate effective communication among the team members and the client. Also included in this section is a description of the hardware and software resources required for the successful completion of the project.

## 3.1.1. Project Personnel Organization

Table 1. Members’ main work domain

|  |  |
| --- | --- |
| **Team member** | **Main work domain** |
| Francois D’Ugard | Migration Management, Communications Network |
| Dr. Ming Zhao | Mentor, Client and Guidance |

Table 2. Members’ roles

|  |  |
| --- | --- |
| **Team member** | **Role** |
| Francois D’Ugard: | Lead Developer, Tester, Project Manager |
| Dr. Ming Zhao | Mentor, client |

## 3.1.2. Hardware and Software Resources

The following section lists the hardware and software resources necessary for the successful completion of the project.

* Hardware
  + 1 personal computer for development, testing, and demos. Minimum requirements: Dual-core CPU @ 1.2 GHz, 2GB RAM, 128GB HDD.
  + 2+ servers where the cloud infrastructure will be set up. Minimum requirements: Dual-core CPU @ 1.4 GHz, 8GB RAM, 500 GB HDD, 2 x 1Gbps PCI LAN interfaces.
* Software
  + OpenStack cloud computing platform.
  + IPOP Peer to peer VPN networking controller
  + Graphtool Python library for efficient network analysis
  + Python 2.7
  + Ubuntu Server 12.04 or 14.04 LTS.
  + Google Drive, Google Talk, and Gmail for collaboration.
  + Microsoft Word, Microsoft Excel, Microsoft PowerPoint, and Adobe Reader
  + StarUML - UML modeling tool.
  + Unittest - a unit test framework for Python.
  + Pencil for user interface mockups.

## 3.2. Identification of Tasks, Milestones, and Deliverables

All tasks are identified with a unique string in the format of component number, milestone number, and task number i.e. C#M#T#.

* Setup Development Environment
  + Milestone 1: Complete setup of development environment and network configuration and setup NFS file system to support live migration capabilities of OpenStack.
    - C1M1T1: Install Hardware Components
    - C1M1T2: Install Ubuntu 12.04 on all development machines
    - C1M1T3: Configure Development Network
    - C1M1T4: Deploy OpenStack cloud to all development machines
    - C1M1T5: Setup Network File sharing service for live migration
* Communications Network: Design and implementation of a distributed P2P VPN communications network that obfuscates communications with collaborating virtual machines and prioritizes communication reestablishment by communication history.
  + Milestone 2: Design distributed collaborative communication network using IPOP P2P VPN.
    - C3M2T1: Design modifications to IPOP controller
    - C3M2T2: Design link restoration algorithm based on communications history
    - C3M2T3: Design communications obfuscation algorithm to hide mission critical communications between collaborating virtual machines.
  + Milestone 3: Implement Communications Network Component
    - C3M3T1: Implement Communications Network link reestablishment Algorithm
    - C3M3T2: Implement Communications Network obfuscation Algorithm
    - C3M3T3: Implement Command line interface for Communications Network component
  + Milestone 4: Integrate Communications Network Component into OpenStack system
    - C3M4T1: Systems integration and testing.

### 3.2.1 Project Milestones

1. Complete setup of development environment and network configuration and setup NFS file system to support live migration capabilities of OpenStack.
2. Communication network using IPOP P2P VPN Design complete
3. Implement Communications Network Component
4. Create Unit Tests for Communications Systems
5. Integrate Communications Network Component into OpenStack system

### 3.2.2. Deliverable Timeline:

9/8/2014

Feasibility Study and Project Plan. First draft.

Requirements Document. First draft.

Feasibility Study and Project Plan. In-class presentation.

9/15/2014

Feasibility Study and Project Plan. Second draft.

9/22/2014

Feasibility Study and Project Plan. Final draft.

Feasibility Study and Project Plan. In-class presentation

9/29/2014

Requirements Document. Second draft.

Requirements Analysis.

10/6/2014

Requirements Document. Final draft.

Requirements Analysis. In-class presentation.

Design Document. First draft.

10/20/2014

Design Document. Second draft.

System and Detailed Design. In-class presentation.

10/27/2014

Design Document. Final draft.

System and Detailed Design.

Implementation and Unit Testing. First code review.

11/17/2014

Implementation and Unit Testing. Second code review.

In-class presentation.

11/24/2014

Implementation and Unit Testing. Final code.

Implementation and Unit Testing.

Integration and System Testing. First code review.

# Appendix

## 4.1. Appendix A - Project Schedule

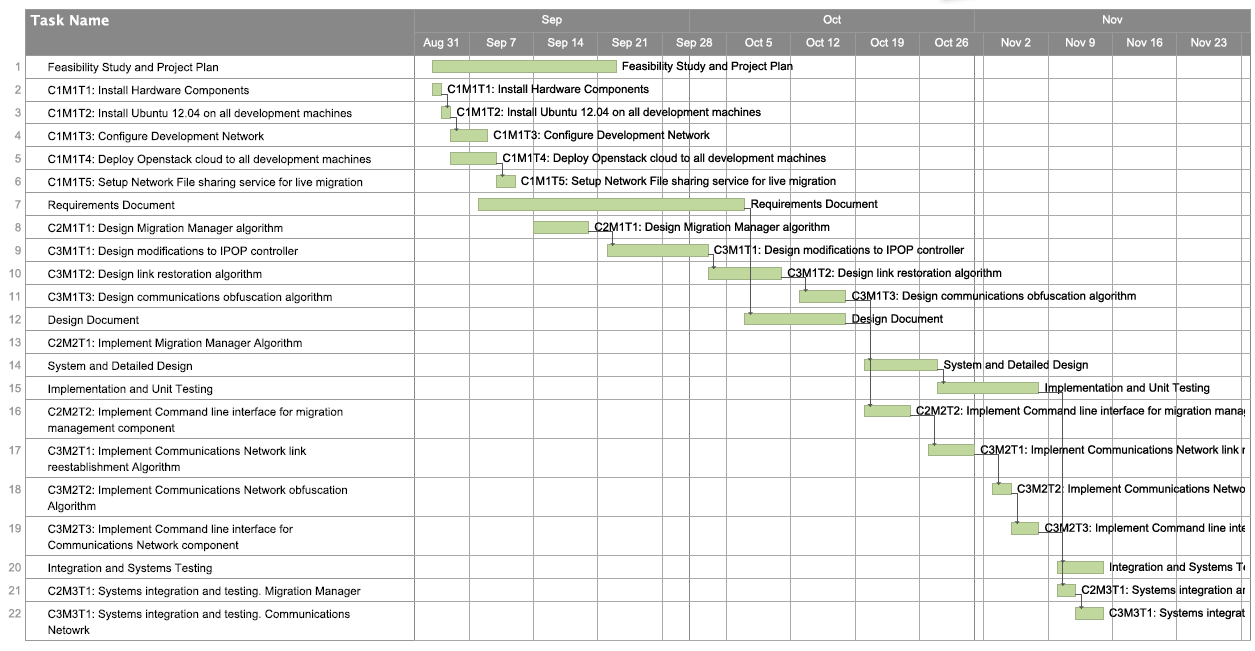


Figure 4.1 - Project Gantt Chart

## 4.2. Appendix B - Feasibility Matrix

**Uninterrupted Communication**

Candidate A: Use of central host list server.

Candidate B: Use VPN over P2P overlay.

|  |  |  |  |
| --- | --- | --- | --- |
| **Feasibility criteria** | **Max.** | **Candidate A** | **Candidate B** |
| Operational feasibility | 3 | 3 | 3 |
| Technical feasibility | 4 | 2 | 4 |
| Economic feasibility | 3 | 2 | 2 |
| **Score** |  | **7** | **9** |

Figure 4.2 - Feasibility Matrix

## 4.3. Appendix C - Cost Matrix

|  |  |  |
| --- | --- | --- |
| **Resource** | **Quantity** | **Cost** |
| Server | 2 | $5,000 |
| Personal Computer | 1 | $1,400 |
| Software | Open Source | $0 |
| Personnel (Hours @ $40) | 480 | $19,200 |
| **TOTAL** |  | **$30,600** |

Figure 4.3 - Cost Matrix

## Appendix D - Diary of Meetings

9/05/2014

Present: Dr. Ming Zhao, Francois D’Ugard

Location: ECS 363

Time: 3:00 PM - 3:50 PM

Highlights:

* Discussed Current status of project
* Discussed challenges regarding OpenStack Configuration
* Discussed Project requirements

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