Contents

Contents xi

1 Introduction and Objectives 1

1.1 Objectives 8

1.2 Summary of the state of the art 10

1.2.1 Automated Power Management 10

1.2.2 Facilitating Power Management 12

1.2.3 Elastic Virtual Clusters 13

1.3 Organization of this Document 14

2 An Energy Management System for Cluster Infrastructures 17

2.1 Introduction 18

2.2 Power management approach 19

2.3 Related Work 20

2.4 System description 22

2.4.1 CLUES Scheduler 24

2.4.2 Resource Manager Connectors 28

2.4.3 Hook system 30

2.4.4 Sensor System 31

2.5 Mixed cluster 31

2.6 Results Evaluation 32

2.6.1 Cluster 1 32

2.6.2 Cluster 2 34

2.7 Conclusion and Future Jobs 37

3 An Economic and Energy-Aware Analysis of the Viability of Outsourcing Cluster Computing to the Cloud 39

3.1 Introduction . . . 40
3.2 Related work . . . 42
3.3 The Total Cost of Ownership (TCO) of an HPC Cluster . . . 43
3.3.1 The Cost of an HPC Cluster on the Cloud . . . 46
3.4 Cost Analysis of Moving HPC to the Cloud . . . 48
3.4.1 Supporting Data for the Case Study . . . 51
3.4.2 Comparing clusters . . . 53
3.5 Discussion . . . 56
3.6 Conclusions . . . 57

4 EC3: Elastic Cloud Computing Cluster 59

4.1 Introduction . . . 60
4.2 Related Work . . . 61
4.3 EC3: Elastic Cloud Computing Cluster . . . 63
4.3.1 Virtual Infrastructure Deployment . . . 64
4.3.2 Elasticity Rules . . . 65
4.3.3 Overall Architecture . . . 68
4.3.4 Connecting to the IaaS . . . 70
4.4 Case studies . . . 71
4.4.1 Clusters with long usage period . . . 71
4.4.2 Ad-Hoc Cluster . . . 73
4.5 Conclusion and Future work . . . 76

5 Automatic Consolidation of Virtual Machines in On-Premises Cloud Computing Platforms 79

5.1 Introduction . . . 80
5.2 Related works for the problem of redistributing the VMs . . . 82
5.3 VMs distribution among physical hosts . . . 85
5.4 The Virtual Machine Consolidation Agent . . . 86
5.4.1 Connector to the platform . . . 87
5.4.2 Monitoring system . . . 88
5.4.3 Analysis of the platform and planning the migrations. . . . 89

5.4.4 Execution of the migration plan 94
5.5 Integrating VMCA with the policies of the platform 94
5.6 Experiments with VMCA 95
5.6.1 Selecting a configuration of parameters 96
5.6.2 Tests into the production platform 99
5.7 Conclusions and future work 102

6 Automatic Memory-based Vertical Elasticity and Overcommitment on Cloud Platforms 105

6.1 Introduction 106
6.2 Related work 107
6.3 Problem, Methods & Materials 109
6.4 Architecture 111
6.4.1 Oversubscription via Stolen Memory 114
6.5 Assessment via Case Studies 116
6.5.1 Fully Elastic Virtual Clusters for Grid Infrastructures 116
6.5.2 Addressing Memory Overcommitment via Live Migration 119
6.6 Conclusion and Future Works 124

7 Discussion of the Results 125

7.1 Putting Things Together: the Multi-Elastic Data Center 125
7.2 Summary of the Achievements 129
7.3 Publications 130
7.4 Products 131
7.4.1 CLUES 131
7.4.2 EC3 134
7.4.3 VMCA 135
7.4.4 CloudVAMP 135
7.5 Future Directions 136
7.5.1 Future Research Lines 136
7.5.2 Future Improvements for the Products 138

8 Conclusions 141

Bibliography 145

Index 159