1. What is Cloud Computing (CC)? 3

1.1. Utility Computing First 3

1.2. The New Features of Cloud Computing (CC) 4

1.3. Cloud Service Provider (CSP) 5

1.3.1 Thin Provisioning 6

1.4. CC via a CSP (not via own cloud OS) 8

1.4.1 Public Cloud 8

1.4.2 Private Cloud 8

1.4.3 Hybrid Cloud 9

1.4.4 Infrastructure-as-a Service (IaaS) 9

1.4.4.1 Resource Administration by the User 10

1.4.4.2 The Role of the CSP 11

1.4.4.3 Nested Virtualization 11

1.4.5 Platform-as-a-Service (PaaS) 11

1.4.6 Software-as-a-Service (SaaS) 12

1.4.7 Special CSP Access-Offers 13

1.4.7.1 Community Cloud 13

1.4.7.2 Virtual Private Cloud 14

1.4.7.3 Multi Cloud 14

1.5. CC with own Cloud OS (not via CSP) 15

2. What are the Pros and Cons of CC? 16

2.1. CC via CSP 17

2.1.1 Pros 17

2.1.1.1 Server Consolidation via VM Migration 19

2.1.2 Cons 19

2.1.2.1 Vendor-Lock-in 20

2.2. CC with own Cloud OS 20

2.2.1 Pros for own Cloud OS 20

2.2.2 Cons for own Cloud OS 22

3. Technologies of CC 24

3.1. Common Technologies for CSP Clouds and own Cloud OS 24

3.2. Tenant and Multi-Tenancy 24

3.2.1 Tenant 24

3.2.2 Multi-Tenancy 25

3.2.3 Resource Pooling 26

3.3. Linux Containers (LXCs) 27

3.3.1 Cgroups 27

3.3.2 Namespace Isolation 27

3.3.3 LXC Functionalities 28

3.4. Virtualization by means of VMs 29

3.5. Auto-scaling 30

3.6. Disjoint Software Technologies 31

3.7. Specific Technologies for CC via CSPs 31
3.7.1 Language and Platform-specific APIs 31
3.8. Specific Technologies for CC via own Cloud OS 32
3.8.1 Location of own Cloud OS in the Software Stack 32
3.8.2 Basic Services in own Cloud OS 34

4. Virtual Machines (VMs) 35

4.1. What is a VM? 36
4.2. Advantages of Virtualization 38
4.2.1 Setup of a VM 41
4.3. Disadvantages of Virtualization 42
4.4. Host OS and Guest OS 42
4.5. Hypervisor 44
4.5.1 ESXi, Hyper-V and KVM/QEMU 47
4.6. Paravirtualization 48
4.6.1 VirtIo for Paravirtualization 50

5. Server Virtualization 50

5.1. Comparison between Classical Computer and Virtualized Server 51
5.2. How Host OS sees Guest OSes, QEMUs and User Applications 54
5.3. Privileged CPU instructions in Guest OS 54
5.4. Server Virtualization in a Cloud 55
5.5. Virtualization of Memory, CPU and IO 58
5.5.1 Memory Virtualization 59
5.5.1.1 Virtual Shared Memory 60
5.5.2 CPU Virtualization 60
5.5.3 IO Virtualization 61
5.5.3.1 Example of IO Virtualization by Sending an Email from a VM 62
5.6. Hardware Accelerators for Server Virtualization 62
5.6.1 Accelerators for Memory Virtualization 63
5.6.2 Accelerators for CPU Virtualization 63
5.6.3 Accelerators for IO Virtualization 64
5.6.3.1 SR-IOV 64
5.6.4 Status of Hardware Accelerators for Server Virtualization 65
5.6.5 Summary of Hardware Accelerators 66
5.7. Inter-vCPU and Inter-VM Communication on the Same Server 67
5.7.1 Inter-VM Communication Without Ivshmem 68
5.7.1.1 Tap Device 69
5.7.1.2 Macvlan Driver 69
5.7.1.3 Macvtap 69
5.7.1.4 Inefficient Inter-VM Communication as Result 70
5.7.2 Inter-VM Communication With Ivshmem 72
5.8. Inter-VM Communication between Servers without Cloud OS 74
5.9. Inter-VM Communication between Servers with Cloud OS 76
5.9.1 Inter-VM Communication between Servers with OpenStack 77
6. Overview on OpenStack and its Services 81

6.1. REST Protocol 82

6.2. Calling and Controlling an OpenStack Service 83

6.2.1 Extended UUID Usage for Information Items 84

6.2.2 Calling via REST API 85

6.2.3 Calling from Host OS Shell 86

6.2.4 Calling via GUI 87

6.2.5 Caveats 88

6.2.6 Calling via CLI 88

6.2.7 Calling via UUID 88

6.3. Overview on OpenStack Services 88

6.4. The 10 Most-Important OpenStack Services 92

6.5. The Smallest Possible OpenStack System 97

6.6. Controller Node and Other Nodes 98

6.7. Minimum Software Stack in a Compute Node 100

6.8. Intra-Service and Inter-Service Communication 101

6.8.1 oslo.messaging 101

6.8.1.1 Advanced Message Queuing Protocol (AMQP) 102

6.8.1.2 ZeroMQ Message Transfer Protocol (ZMTP) 103

6.8.1.3 Notifications 104

6.9. The Horizon Service 104

6.9.1 Horizon GUI 105

6.9.2 List of Tabs and Sub-tabs for the User GUI 108

6.9.2.1 Compute Tab 109

6.9.2.2 Volume Tab 109

6.9.2.3 Network Tab 110

6.9.2.4 Object Store Tab 111

6.9.3 List of Tabs and Sub-tabs for the Admin GUI 111

6.9.3.1 Overview Tab 111

6.9.3.2 Compute Tab 111

6.9.3.3 Volume Tab 113

6.9.3.4 Network Tab 113

6.9.3.5 System Tab 114

6.9.4 Horizon Projects (Tenants) And User Authorization 115

6.9.5 Extensions to Horizon 116

6.9.6 Abstract Service API of Horizon 117

6.9.7 Horizon GUI Terminology 117

6.10. General OpenStack Terminology 119

6.11. The Nova Service 121

6.11.1 Nova Compute Cells 121

6.11.2 Nova Internal Setup 123

6.11.3 Parallel Processing Inside of Nova 124

6.11.4 Communication Between Nova Components 125

6.12. The Neutron Service 126

6.12.1 Neutron Task List 126

6.12.2 Neutron Software Defined Networks 128