Unit 2: Cloud Computing

Virtualization and Cloud Infrastructure

Course Material

Contents

1 Introduction to Virtualization

Virtualization creates virtual versions of physical computing resources, allowing multiple virtual systems to run on a single physical machine. This maximizes resource utilization and provides flexibility in modern computing environments.

1.1 Physical vs. Virtual Infrastructure

Aspect	Physical	Virtual
Hardware	Dedicated physical devices required	Resources abstracted and pooled
Provisioning	Time-consuming and costly	Quick and scalable on demand
Scalability	Limited by physical constraints	Highly flexible and dynamic
Access	Requires physical presence	Remote access from anywhere
Security	Physical controls (access, surveillance)	Digital measures (encryption, firewalls)
Recovery	Manual, difficult	Automated, cloud-based
Utilization	Often under-utilized	Efficient resource pooling
Cost	High capital expenditure	Pay-as-you-go model

Table 1: Physical vs. Virtual Infrastructure

1.2 Virtual Machine (VM)

A **Virtual Machine** is a software-based emulation of a physical computer with its own virtual CPU, memory, storage, and network interfaces, running on a physical host system.

2 Virtualization Architecture

2.1 Virtualization Layer

The virtualization layer handles three key functions:

1. Creation of virtual machines
2. Allocation of resources (CPU, memory, storage, network)
3. Coordination and isolation between VMs

2.2 Traditional vs. Virtualization Architecture

Key Differences:

- Traditional: Single instance, tightly coupled, under-utilized
- Virtualization: Multiple VMs in parallel, loosely coupled, efficient utilization

3 Hypervisor Technology

A **Hypervisor (VMM)** is software that manages multiple operating systems on a single physical machine.

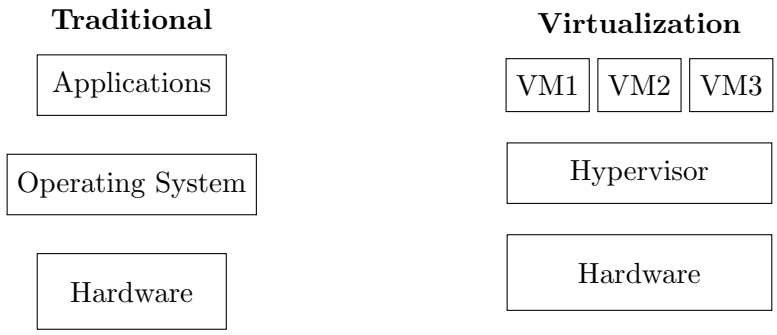

Figure 1: Traditional vs. Virtualization Architecture

3.1 Types of Hypervisors

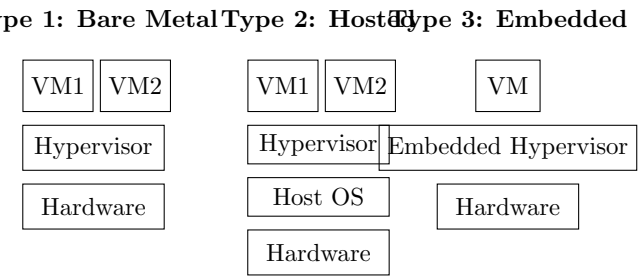

Figure 2: Hypervisor Types

Feature	Type 1	Type 2	Type 3
Performance	High	Moderate	Very High
Overhead	Low	Higher	Minimal
Use Case	Data centers	Desktop, testing	Embedded systems
Examples	VMware ESXi, Hyper-V	VirtualBox, VMware Workstation	Automotive, IoT

Table 2: Hypervisor Comparison

4 Virtualization Techniques

4.1 Full Virtualization

Provides complete hardware abstraction; guest OS runs unmodified.

Process: VM attempts privileged instruction → Trap to hypervisor → Hypervisor emulates → Result returned

4.2 Para-virtualization

Guest OS is modified to communicate directly with hypervisor via hypercalls for better performance.

5 Application Virtualization

Separates applications from the OS, enabling isolated execution without full OS virtualization.

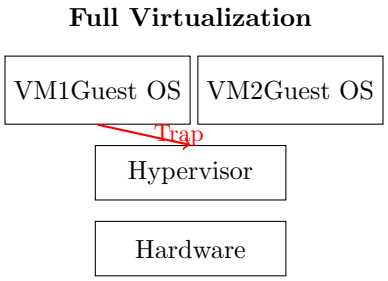

Figure 3: Full Virtualization - Trap and Emulate

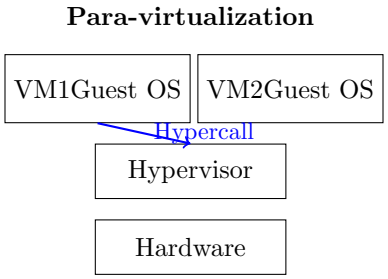

Figure 4: Para-virtualization - Hypercalls

5.1 Types

1. **Application Streaming**: On-demand delivery from central server (e.g., Microsoft App-V)
2. **Thin Client**: Application runs on server; only UI displayed on client
3. **Terminal Services**: Multiple users access applications via remote desktop
4. **Desktop Virtualization (VDI)**: Full desktop OS virtualized (e.g., VMware Horizon)
5. **Sandboxing**: Isolated environment for testing/security (e.g., Docker)

6 Storage Virtualization

Abstracts physical storage into a unified, logical pool for centralized management and dynamic allocation.

6.1 NAS vs. SAN

6.2 Key Concepts

- **Data Tiers**: Hotline (frequent access, SSD) vs. Coldline (archival, tape)
- **Storage Pooling**: Aggregating multiple devices into single virtual resource
- **Benefits**: Centralized management, easy backup/recovery, extended device lifetime

7 Network Virtualization

Creates virtual networks independent of physical infrastructure.

Aspect	Full Virtualization	Para-virtualization
Guest OS	Unmodified	Modified
Performance	Lower (trap overhead)	Higher (direct calls)
Hardware Access	Indirect (emulation)	Direct (hypercalls)
Compatibility	Any OS	Only modified OS

Table 3: Full vs. Para-virtualization

Aspect	NAS	SAN
Type	File-level storage	Block-level storage
Protocol	NFS, SMB/CIFS	iSCSI, Fibre Channel
Performance	Moderate	High
Cost	Affordable	Expensive
Use Case	File sharing, collaboration	Databases, high-performance apps

Table 4: NAS vs. SAN

7.1 Traditional vs. Modern Network Virtualization

Traditional (TNV):

- Virtual switches within hypervisor
- VMs on same host communicate via virtual switch
- Cross-host communication requires physical network
- VLAN support for segmentation

Modern (MNV):

- Software-defined networking across hosts
- Encrypted communication between VMs
- Dynamic routing and load balancing
- Examples: VXLAN, VMware NSX

7.2 Communication Scenarios

Case I - Same VLAN, Same Host: Direct communication via virtual switch

Case II - Same VLAN, Different Host:

- TNV: VM → LVS → Physical Switch → Router → Physical Switch → LVS → VM
- MNV: Encrypted path with enhanced security

Case III - Different VLAN, Same Host: Requires routing through logical router

7.3 VLAN Benefits

Virtual LANs enable network segmentation, broadcast isolation, improved performance, and flexible management regardless of physical topology.

8 Service Virtualization

Simulates dependent components (APIs, databases) for testing and development without actual services.

8.1 Key Concepts

- **VM Square**: Catalog of available virtual services
- **Multi-tenancy**: Multiple customers sharing infrastructure with isolation
- **SLA**: Service level agreements defining availability, performance, support
- **Monitoring**: Continuous tracking of performance and compliance
- **Data Commingling Risk**: Ensure proper isolation to prevent data mixing

8.2 Benefits

Enables parallel development, reduces costs, removes dependency bottlenecks, and allows testing without production impact.

9 Benefits of Virtualization

1. **Server Consolidation**: Combine multiple physical servers into fewer machines
2. **Scalability**: Vertical (add resources) and horizontal (add instances) scaling
3. **Customization**: Flexible resource allocation, OS selection, network configuration
4. **Disaster Recovery**: Easy backup and restoration
5. **Cost Savings**: Reduced hardware, power, and management costs
6. **Hardware Independence**: VM portability across different hardware
7. **Isolation**: Contained failures and enhanced security

10 Challenges and Considerations

10.1 Performance

Small overhead from hypervisor layer; mitigate with hardware-assisted virtualization (Intel VT-x, AMD-V)

10.2 Security

Hypervisor vulnerabilities, VM escape risks, inter-VM attacks; requires patching, encryption, segmentation

10.3 Management

License complexity, specialized skills required, need for ongoing training

11 Future Trends

- **Containers**: Lightweight, faster startup (Docker, Kubernetes)
- **Edge Computing**: Virtualization at edge locations for IoT and 5G
- **AI-Driven Management**: Predictive allocation, automated optimization
- **Serverless**: Function-as-a-Service with complete infrastructure abstraction

12 Summary

Virtualization abstracts physical resources into logical, software-defined resources. Three hypervisor types (Bare Metal, Hosted, Embedded) enable various virtualization approaches (compute, storage, network, application, service). Key benefits include consolidation, scalability, and cost savings, with challenges in performance, security, and management. Future trends point toward containers, edge computing, and AI-driven automation.

13 Review Questions

1. Compare physical and virtual infrastructure across multiple dimensions.
2. Describe the three hypervisor types with examples and use cases.
3. Differentiate full virtualization from para-virtualization.
4. Explain NAS vs. SAN in storage virtualization.
5. How does Modern Network Virtualization improve upon Traditional approaches?
6. What are the benefits of service virtualization for development teams?
7. List three benefits and three challenges of virtualization.
8. When might physical machines be preferred over virtual machines?

14 Glossary

Virtualization Creating virtual versions of physical resources

VM Software-based emulation of a physical computer

Hypervisor Software managing virtual machines

Full Virtualization Unmodified guest OS using trap-and-emulate

Para-virtualization Modified guest OS using hypercalls

NAS Network Attached Storage - file-level

SAN Storage Area Network - block-level

VLAN Virtual Local Area Network

SLA Service Level Agreement

VDI Virtual Desktop Infrastructure