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GENERAL DOCUMENTATION

Renewal of the IT Infrastructure of the Royal Institute for Tourism & Hospitality in Thimphu/Bhutan

presented by

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Thimphu/Bhutan, May 2016

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List of Abbreviations

AD	Active Directory
ADA	Austrian Development Agency
DNS	Domain Name System
DHCP	Dynamic Host Configuration Protocol
GPO	Group Policy Object
HDD	Hard Disk Drive
IP	Internet Protocol
iSCSI	Internet Small Computer Systems Interface
ISP	Internet Service Provider
LA	Link Aggregation
LACP	Link Aggregation Control Protocol
LAN	Local Area Network
LAG	Link Aggregation Group
MAC	Media Access Control
NAS	Network Attached Storage
NIC	Network Interface Card
OS	Operating System
OSI	Open Systems Interconnection
PoE	Power over Ethernet
RAID	Redundant Array of Independent Disks
RITH	Royal Institute of Tourism and Hospitality
VLAN	Virtual Local Area Network
VM	Virtual Machine
WAN	Wide Area Network

1 Introduction

1.1 Overview

A working and up-to-date IT infrastructure for a school is one of the most essential things these days. This practical training deals with the renewal of the IT infrastructure of the Royal Institute of Tourism and Hospitality (RITH) located in Thimphu/Bhutan. Moreover a school management system had to be introduced.

Based on the existing hardware at RITH and the requirements to the IT infrastructure, a new IT infrastructure has been created. Crucial factors regarding the selection of the new hardware components were the costs, support availability for Bhutan, size and weight of the component and a good balance between functionality of the IT infrastructure and the difficulty of maintenance. The IT infrastructure plan will be explained in detail. Exact configurations of the network infrastructure are also described within this report.

The new IT infrastructure plan has been implemented at RITH and the new hardware installed. Tuition has been given to the IT administrators at RITH about the operation of the IT infrastructure and about new technologies, that haven't been known yet. Moreover important documentation has been created regarding the operation and maintenance of specific IT infrastructure components.

This practical training deals with a part of a project that was founded in 2008 by a consortium between the Tourism Schools Salzburg, the degree course IMT at Salzburg University of Applied Sciences and the Foundation Urstein. The funding of the project was supported by the Austrian Development Agency (ADA). The goal of this sub-project is the renewal of the IT infrastructure at the RITH in Thimphu/Bhutan.

2 Selection of used technologies

2.1 Layer 2 versus Layer 3 device

Before explaining Virtual Local Area Networks (VLANs) in detail, it is important to understand the concept of switches. A network switch is used to connect several devices together on a computer network. When speaking about the functionality "switching", a Layer 2 device of the Open Systems Interconnection (OSI) model is meant. When performing "switching" the switch uses hardware addresses, in particular the Media Access Control (MAC) address, to forward data from one port to another.
Some switches, also known as Multilayer Switches or Layer 3 switches, support "routing functionality", thus referring to a Layer 3 device of the OSI model. A Layer 3 device uses Internet Protocol (IP) addresses to perform packet forwarding. The most widely known L3 device is the router [1].

Switches with Layer 2 functionality are used to connect same subnets to each other. In order to enable data communication between different IP subnets, a Layer 3 device with routing functionality is needed! Moreover it is important to know, that L2 switches, on the contrary to routers, do not separate broadcast domains. This means, that broadcast messages sent by a client do not traverse a router by default [1].

2.2 VLANs

A VLAN is used to allow data communication for a group of devices (e.g. computer, server, firewall and more) as if they were attached to the same wire, although in reality they can be connected to totally different LAN segments (e.g. one device is located in building A and the other device in building B on the other side of the street).
Most of the time VLANs are associated with IP subnets. A VLAN defines an own broadcast domain in a Layer 2 network. VLANs are typically defined at switches and are based on logical instead of physical connections.
Figure 2.1 shows three different VLANs that span multiple floors [2].

2.2.1 Trunks and tagged VLANs

Trunk links are required to pass several VLANs from one switch to another when using only one logical connection. On a Cisco switch a port can be configured for either access or trunk mode. Access ports belong to only one VLAN and frames exiting such a port are not tagged (marked). Trunk ports on the other way allow the transmission

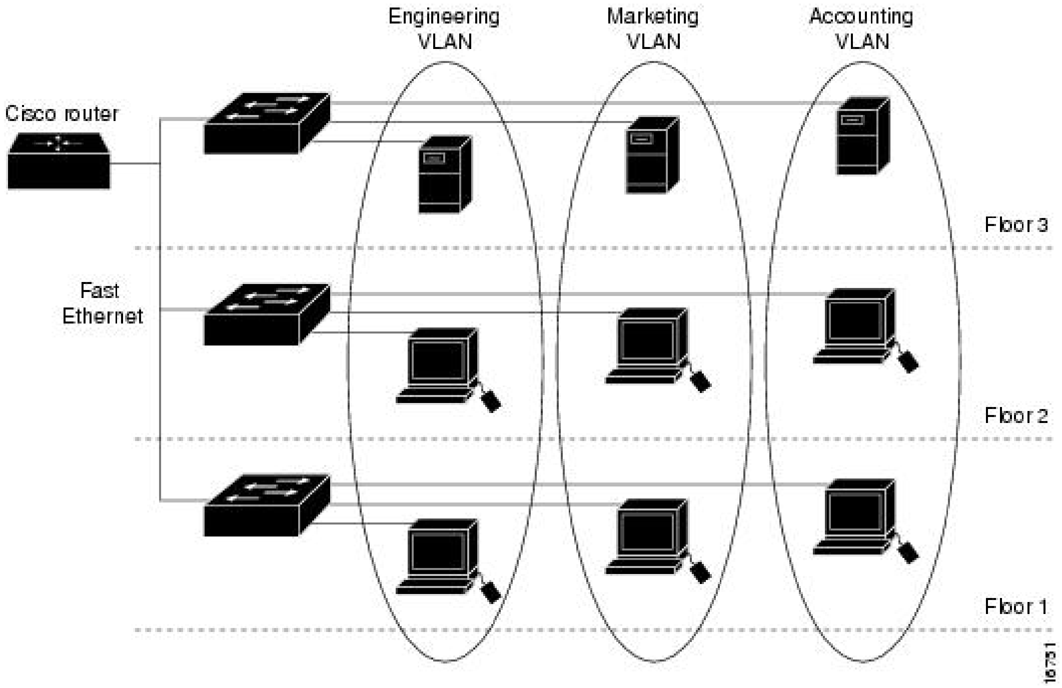


Figure 2.1: Example of VLANs [2]

of several VLANs. In order to be able to distinguish the VLAN origin of the frame it is marked with a VLAN tag. This marking procedure is called tagging and uses some tagging mechanism (ISL or 802.1Q, whereby 802.1Q is the most commonly used).
A tagged and untagged frame mainly distinguishes between having a VLAN tag or not.

Fig. 2.2 shows the concept of tagging by looking at the most common Ethernet frame type Ethernet-II (IEEE 802.3) including an inserted 802.1Q VLAN tag [3].

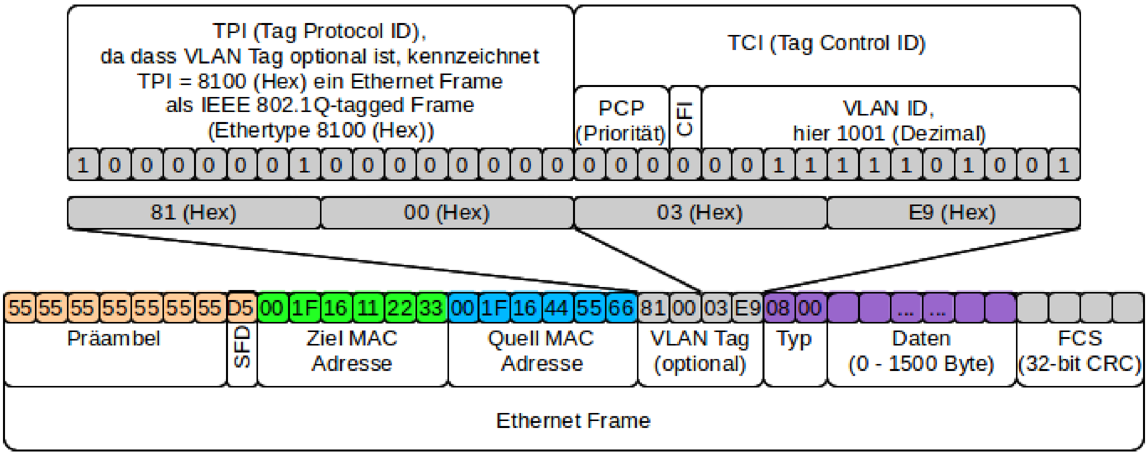


Figure 2.2: Ethernet-II frame with 802.1Q VLAN tag [4]

Native VLAN

The only VLAN that is not tagged on a trunk is called the native VLAN. This means that all packets belonging to the native VLAN do not have a VLAN tag. When configuring a trunk on a Cisco switch and not specifically defining a native VLAN, the native VLAN will be VLAN 1.

2.3 Hypervisor

A hypervisor is a piece of software that allows for one physical device (e.g. computer or server) to share its resources amongst several Virtual Machines (VMs) running on that physical device.
Speaking of terminology, the server that is running the hypervisor is called host machine and the VMs are called guest machines. As displayed in fig. 2.3 the hypervisors are divided into Type-1 (native or bare-metal) hypervisors and Type-2 (hosted) hypervisors [5].

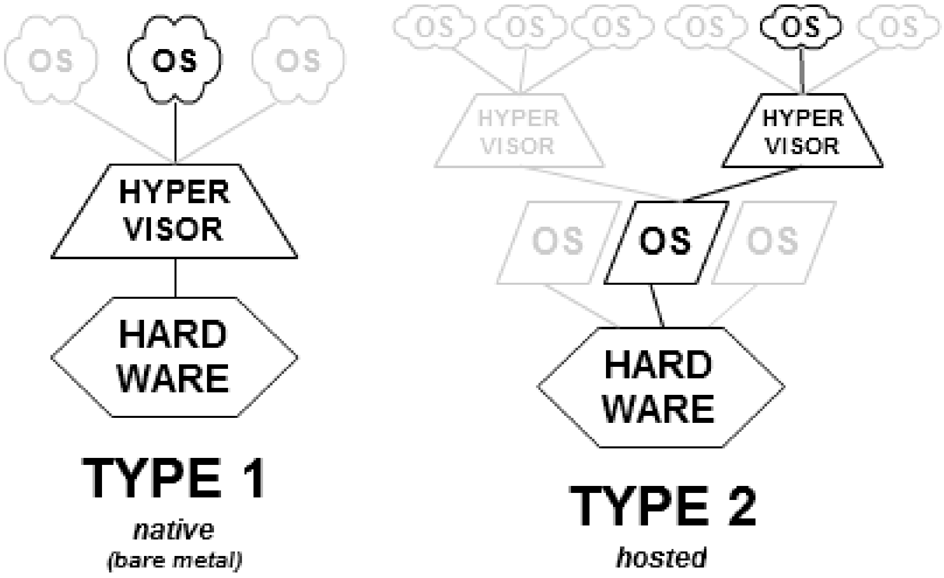


Figure 2.3: Difference between Type-1 and Type-2 hypervisor [6]

Type-1 Hypervisor

When installing this type, the hypervisor is directly installed as an operating system. A huge advantage is, that the hypervisor can directly communicate with the underlying physical hardware. These physical hardware resources are then *paravirtualized* and provided to the virtual machines. This type of hypervisor is the preferred method for productive server environments. One hypervisor of this type is VMware ESXi, which has also been used within the IT infrastructure at RITH [5].

Type-2 Hypervisor

When speaking of this type, a hypervisor that can be directly installed on an operating system is meant. Two popular freeware products are VMware Player and Oracle VM VirtualBox. These types of hypervisor are not used for productive server environments. They are more used to quickly do some tests and experiments without crashing the own operating system [5].

An example would be that someone would like to test a linux operating system. He/she then installs a Type-2 Hypervisor on his/her operating system (e.g. Windows 10) and creates a VM for Linux. After that he/she is able to do everything within this VM without affecting his/her used operating system Windows 7.

Paravirtualization Tools

These tools (in case of VMware also called VMware Tools) are installed on the VMs to perfectly support the paravirtualized hardware, that is provided by the hypervisor [5].

The following shows an example regarding the Paravirtualization Tools.
The hypervisor is accessing the Network Interface Card (NIC) of the physical server and paravirtualizing it, in order to provide this specific NIC to several VMs. When creating the VM, this paravirtualized NIC is then chosen as the network card for the VM. To get optimal performance, the Paravirtualization Tools provide a specific driver for this paravirtualized NIC, that can be installed on the OS of the guest machine.

3 IT Infrastructure

3.1 Final Hardware

Regarding the hardware constellation of the main server and the backup server it was important to have a Redundant Array of Independent Disks (RAID) controller available in order to obtain reliability.

Storage space design:

The Hard Disk Drives (HDDs) on the main server have been configured to operate in a RAID 5. When speaking of RAID 5, there always is one HDD used for parity purposes, whereby the usable capacity is then reduced by the size of one HDD. Furthermore, when configuring a RAID 5, every HDD has to be the same size. The main server has four 1.2 TB HDDs. This results in a net capacity (usable capacity) of 3.6 TB.

The Network Attached Storage (NAS) has two 6 TB HDDs and is configured in a RAID 1. This type of RAID performs a mirroring of hard disks, what means that one HDD can be damaged and the data is still available. Due to the RAID 1 the net capacity of the NAS results in 6 TB.
The backup server is also configured in a RAID 5. Based on the five HDDs with a size of 300 GB each the net capacity is 1.2 TB.
Table 3.1 summarizes the calculations explained above.

Component	**RAID**	**Net capacity**
Main Server	5	3.2 TB
Backup Server	5	1.2 TB
NAS	1	6 TB

Table 3.1: Net capacity of components

The limiting component regarding the storage space was the local storage of the backup server. Due to this reason the decision was made to store the backup files on the NAS. The backup server only hosts the operating system on the local storage and the actual backup files are accessed from the NAS via the Internet Small Computer Systems Interface (iSCSI) protocol.

Table 3.2 shows the hardware components that have been installed at RITH.

Component	Hardware	Specifications	Support
Main Server	Fujitsu PY TX1320M2/SFF	- Intel Xeon E3-1230v5 - 3x 12GB DDR4-2133 - 4x SAS 12G 1.2TB - RAID 5/6 Controller - 2x 1GbE RJ45 interface	5 Year On-Site Service
Backup Server	IBM x3650 M3	- 2x Intel Xeon E5620 @ 2.40GHz - 3x 4GB - 5x SAS 6G 300GB - RAID 5 Controller - 2x 1GbE RJ45 Interface - Redundant power supply	
KVM Switch	Avocent AUTOVIEW 3016		
Provider Modem	RAD ASMi-52		
NAS	1x Synology DS716+		
NAS HDDs	2x Seagate ST6000VN0021 6TB		
Switch	4x Cisco SG300-28		
Switch	2x Cisco SG300-52		
Access Points	6x Cisco WAP200 802.11g PoE		
Access Points	5x Ubiquiti AC AP Pro	Including Power over Ethernet (PoE) Injector	
CCTV	4x Linksys PVC2300		
CCTV PC	Computer		
Printer	Several		
Computer, Laptops	Several		

Table 3.2: Final Hardware

3.2 IT Infrastructure Plan

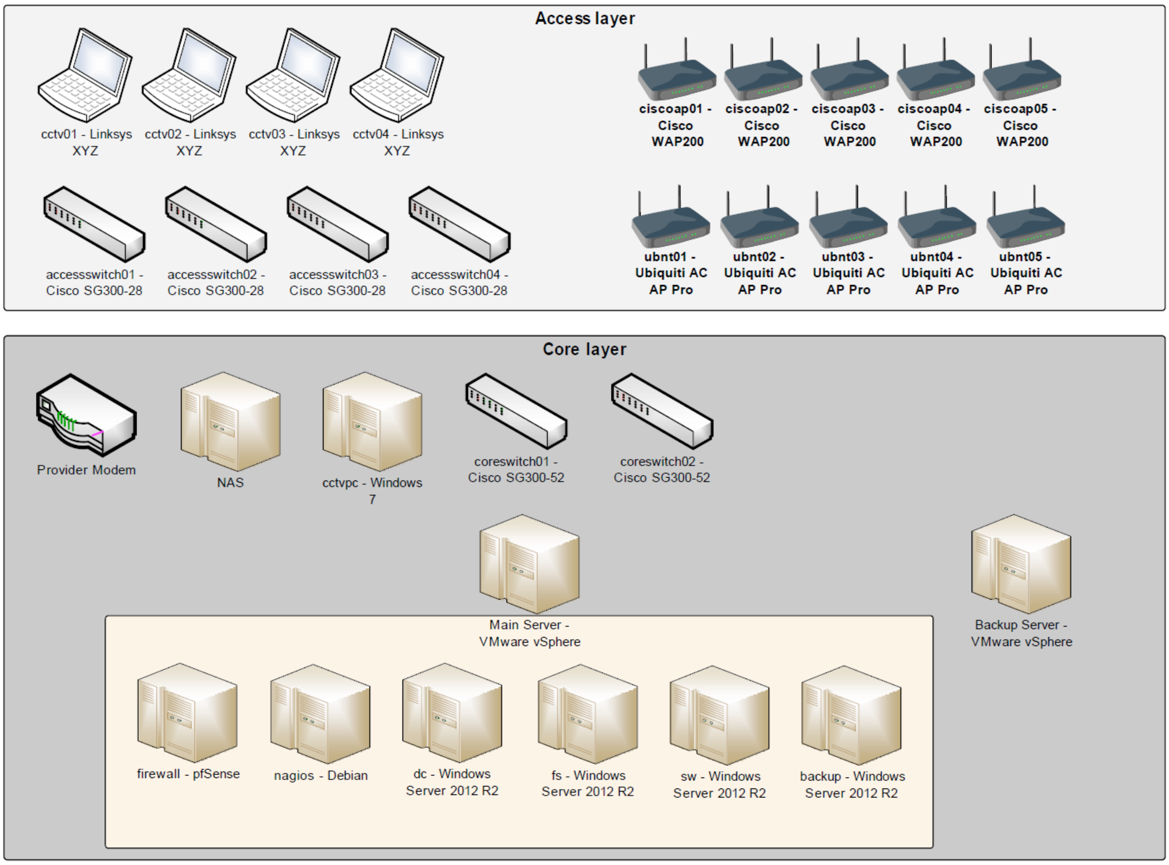

Access layer
cctv01 - Linksys XYZ
cctv02 - Linksys XYZ
cctv03 - Linksys XYZ
cctv04 - Linksys XYZ
ciscoap01 - Cisco WAP200
ciscoap02 - Cisco WAP200
ciscoap03 - Cisco WAP200
ciscoap04 - Cisco WAP200
ciscoap05 - Cisco WAP200
accessswitch01 - Cisco SG300-28
accessswitch02 - Cisco SG300-28
accessswitch03 - Cisco SG300-28
accessswitch04 - Cisco SG300-28
ubnt01 - Ubiquiti AC AP Pro
ubnt02 - Ubiquiti AC AP Pro
ubnt03 - Ubiquiti AC AP Pro
ubnt04 - Ubiquiti AC AP Pro
ubnt05 - Ubiquiti AC AP Pro
Core layer
Provider Modem
NAS
cctvpc - Windows 7
coreswitch01 - Cisco SG300-52
coreswitch02 - Cisco SG300-52
Main Server - VMware vSphere
Backup Server - VMware vSphere
firewall - pfSense
nagios - Debian
dc - Windows Server 2012 R2
fs - Windows Server 2012 R2
sw - Windows Server 2012 R2
backup - Windows Server 2012 R2

Figure 3.1: IT-Infrastrukturplan

Fig. 3.1 shows the software and hardware components that were used within the IT infrastructure. It is divided into an access and a core layer. This abstract representation of the IT infrastructure is used to give an overview. Details like IP subnets, IP addresses, VLANs, switch ports or cabling will be shown later.

3.2.1 IT Infrastructure Plan in detail

Core switch 1, as displayed in the plan, establishes the connection between the modem of the Internet Service Provider (ISP), the main server, the backup server, the NAS, the CCTV PC, core switch 2 and the remaining access switches. The different IP subnets are separated on the switches by use of VLANs.

The Operating System (OS) of the main server as well as the backup server is VMware vSphere, also called ESXi. Due to this virtualization software, also referred to as hypervisor, several VMs can be managed on one single physical server. The main server hosts several VMs which are shortly described in the following paragraphs.

On the VM "firewall.ad.rith.edu.bt" the open source operating system pfSense had been installed. This firewall is used to separate and control the traffic between the Wide Area Network (WAN) and Local Area Network (LAN) network. Moreover it is used to enable communication between the existing VLANs, which is known as VLAN routing. Monitoring of the WAN bandwidth and WAN quality is also part of the firewall. Therefore the built in graphs called "RRD Graphs", available under Status –> RRD Graphs can be used.

The VM "dc.ad.rith.edu.bt" hosts a Windows Server 2012 R2. This server is used as a domain controller for the local Active Directory (AD). The local domain is called "ad.rith.edu.bt". Additionally the server functions as main Domain Name System (DNS) and Dynamic Host Configuration Protocol (DHCP) server for the local network. Group Policy Objects (GPOs) for the AD are also created and managed on the domain controller.

Another Windows Server 2012 R2 is installed on the VM "fs.ad.rith.edu.bt". This server's main purpose is to host a file server. Therefore an additional partition "Data (E:)" has been created to save the shared folders.

The VM "sw.ad.rith.edu.bt" features a Windows Server 2012 R2 too, which is used to host several different software solutions. Currently installed are the UniFi Controller (WiFi controller) for the Ubiquiti access points and the software called Google Active Directory Sync (GADS), which is used to synchronize the user accounts between the Active Directory and Google Apps (Google for Education).
Moreover the windows role IIS has been activated, which provides a web server (like Apache). This web server is used to make the software DokuWiki available over the web on the local network.

On the VM "backup.ad.rith.edu.bt" a Windows Server 2012 R2 is installed as operating system. This VM is used to manage the backup between the main server and the backup server. The software that is used for backup is called Veeam Backup&Replication v9. The backup is done every day at 2am. Details are mentioned in a later section.

The last VM is the "monitoring.ad.rith.edu.bt" on which the operating system Debian 8 has been installed. This VM is used to monitor all the servers and components within the IT infrastructure (e.g. switches, servers, CCTVs and more). The used software is called Check_MK which relies on Nagios as core service. It is available in a package that comes with several other monitoring solutions. This open source package is called Open Monitoring Distribution (OMD) and can be downloaded from the internet.

3.3 Network Infrastructure

3.3.1 IP Subnets, VLANs and Trunks

Within the network infrastructure IP subnets have been created. A VLAN ID and one or no DHCP scopes have been assigned to the IP subnets. The size of the subnet has been designed dependent on the number of hosts. The IP network used as basis for subnetting was the private class B net 172.16.0.0/12.

In order to enable communication between the VLANs, a layer 3 device with routing functionality had to be chosen. Within this IT infrastructure the firewall pfSense is accomplishing that task.

Table 3.3 shows the individual VLANs with additional information.

VLAN	**Name**	**IP Subnet**	**# Hosts**	**DHCP Pool**
5	WAN	nein	nein	nein
10	Management	172.16.10.0/24	254	172.16.10.200 - 172.16.10.230
20	Internal	172.16.20.0/22	1022	172.16.20.50 - 172.16.23.254
30	Unifi	172.16.30.0/27	254	172.16.30.10 - 172.16.30.30

Table 3.3: Übersicht der VLANs

As seen in table 3.3 VLAN 5 is not assigned to an IP subnet. This is, because the only purpose of VLAN 5 is to separate the WAN traffic from the entire other network. The modem of the ISP is connected directly to one port of core switch 1, which has been configured as an access port in VLAN 5. Moreover, only the trunk between core switch 1 and main server, as well as core switch 1 and backup server allows traffic for VLAN 5. On the respective server the trunk then gets split up and only the WAN interface of the VM "firewall.ad.rith.edu.bt", which actually is the WAN interface of the firewall pfSense, gets access to VLAN 5.

By use of this topology it is ensured, that the modem of the ISP is solely connected to the WAN interface of the firewall. The WAN interface of the firewall then receives a DHCP lease of the DHCP server from the ISP.

3.3.1.1 Trunks

The connection between the individual switches, between core switch 1 and main server, as well as between core switch 1 and backup server are configured as a trunk, to transmit more than one VLAN over one logical connection. Moreover the connection between the switches and access points are configured as a trunk too. Table 3.4 shows an overview of all established trunks within this network infrastructure.

HW 1	**HW 2**	**Native VLAN**	**Tagged VLAN**
Coreswitch 1	Coreswitch 2	1	10,20,30
Coreswitch 1	Main Server	1	5,10,20,30
Coreswitch 1	Backup Server	1	5,10,20,30
Coreswitch 1	Accessswitch 1	1	10,20,30
Coreswitch 1	Accessswitch 2	1	10,20,30
Coreswitch 1	Accessswitch 3	1	10,20,30
Accessswitch 4	Accessswitch 1	1	10,20,30
Switch	Cisco WAP200	1	10,20
Switch	Ubiquiti AC AP Pro	30	10,20

Table 3.4: Overview Trunks

The connection between switches and access points has been configured as a trunk in order to transmit VLAN 10 and VLAN 20 tagged. Both the Ubiquiti access points and the Cisco access points distribute two wireless networks. The wireless network with the SSID (name) RITH provides access to VLAN 20, which is used as the default wireless network for students, teacher and members of staff to access the internet and internal network resources. The wireless network with the SSID "RITH Management" connects to VLAN 10 and is only used for management purposes by IT administrators.

The Cisco WAP200 access points receive its management IP address from the DHCP server in VLAN 10. The Ubiquiti access points cannot obtain a management IP address from a network and distribute that network over WiFi at the same time. Therefore a separate IP subnet with the VLAN ID 30 has been created. This VLAN was set as native VLAN on the trunk, because the access point is not capable of maintaining a DHCP lease for its management IP address from a tagged VLAN.

3.3.2 Redundancy and Link Aggregation

One goal when designing the IT infrastructure was to provide as much redundancy as possible, in order to improve availability as well as reliability. Fig. 3.2 shows the cabling of the individual network components.

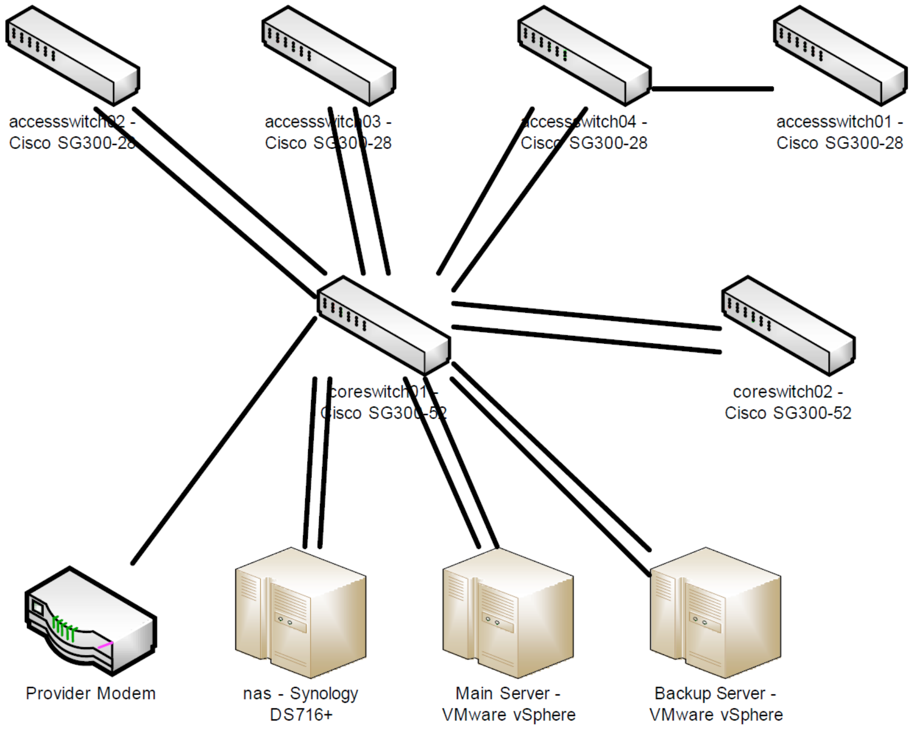


Figure 3.2: Redundancy within the IT infrastructure

To achieve redundancy between the switches, two instead of just one cable were laid. Each port on a switch, that was belonging to the same logical connection, was assigned to a Link Aggregation Group (LAG). On the Cisco SG300 switches those LAGs are called port-channels. The configuration for those port-channels had to be the same on both switches. Furthermore the Link Aggregation Control Protocol (LACP) has been deactivated on both sides. The following listing shows the commands for the Cisco SG300 switch to achieve this configuration. Lines starting with an exclamation mark are comments.

```
! assign the corresponding interfaces to a port-channel
coreswitch01(config)#interface gigabitethernet 49
coreswitch01(config-if)#channel-group 2 mode on
coreswitch01(config-if)#exit
coreswitch01(config)#interface gigabitethernet 50
coreswitch01(config-if)#channel-group 2 mode on
```

```
coreswitch01(config-if)#exit

! set the vlan configuration on the port-channel and not on
! the interfaces
coreswitch01(config)#interface port-channel 2
coreswitch01(config-if)#description "to coreswitch02"
coreswitch01(config-if)#switchport mode trunk
coreswitch01(config-if)#switchport trunk allowed vlan add 10,
                        20,30
```

Speaking of the redundant communication between core switch 1 and main server, as well as core switch 1 and backup server, all configuration had been made on the ESXi. On the core switch 1 itself no special configuration regarding Link Aggregation (LA) had to be made.

ESXi ensures redundancy, that means that all physical links except of one can fail. Moreover it makes load balancing between the physical links, so that the load is distributed equally upon all physical connections.

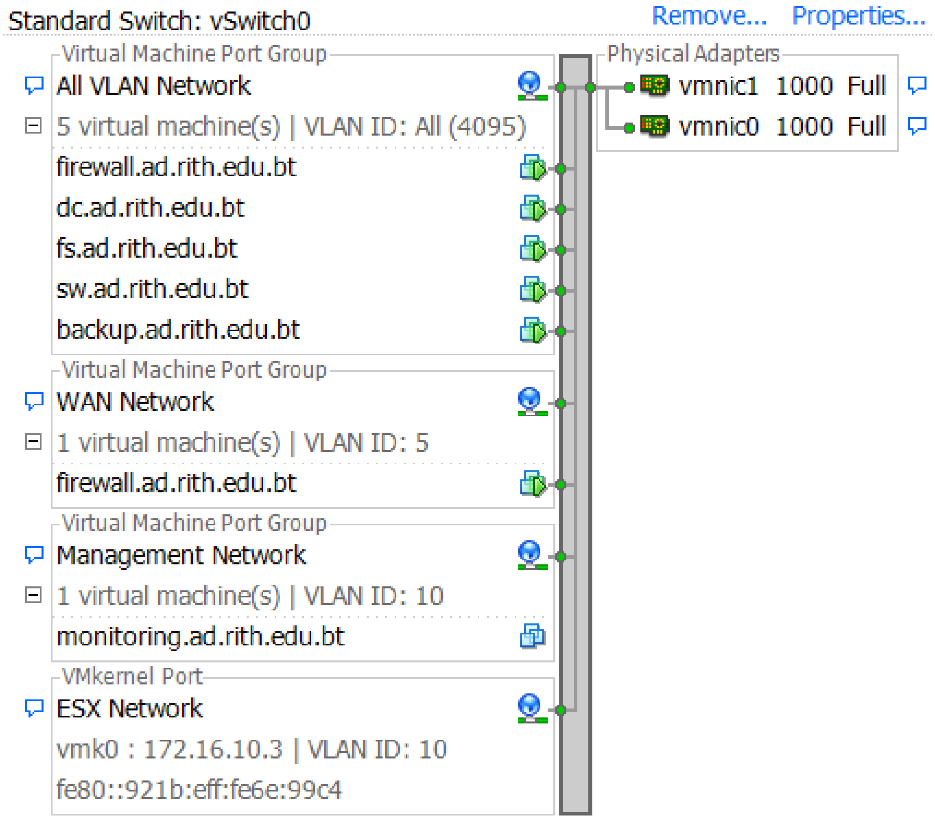
For the connection between core switch 1 and NAS a LAG has been created and LACP enabled in passive mode. This is a requirement from the NAS to get a working LA. In addition, the port-channel connected to the NAS has been configured as an access port in VLAN 10.

The following listing shows the used commands to achieve that configuration on a Cisco SG300 switch.

```
! assign the corresponding interfaces to a port-channel
coreswitch01(config)#interface gigabitethernet 5
coreswitch01(config-if)#channel-group 1 mode auto
coreswitch01(config-if)#exit
coreswitch01(config)#interface gigabitethernet 6
coreswitch01(config-if)#channel-group 1 mode auto
coreswitch01(config-if)#exit

! set the vlan configuration on the port-channel and not on
! the interfaces
coreswitch01(config)#interface port-channel 1
coreswitch01(config-if)#description "to NAS"
coreswitch01(config-if)#switchport mode access
coreswitch01(config-if)#switchport access vlan 10
```

3.3.3 vSphere Network Configuration



Standard Switch: vSwitch0

Virtual Machine Port Group
All VLAN Network
5 virtual machine(s) | VLAN ID: All (4095)
firewall.ad.rith.edu.bt
dc.ad.rith.edu.bt
fs.ad.rith.edu.bt
sw.ad.rith.edu.bt
backup.ad.rith.edu.bt

Virtual Machine Port Group
WAN Network
1 virtual machine(s) | VLAN ID: 5
firewall.ad.rith.edu.bt

Virtual Machine Port Group
Management Network
1 virtual machine(s) | VLAN ID: 10
monitoring.ad.rith.edu.bt

VMkernel Port
ESX Network
vmk0 : 172.16.10.3 | VLAN ID: 10
fe80::921b:eff:fe6e:99c4

Physical Adapters
vmnic1 1000 Full
vmnic0 1000 Full

Figure 3.3: Network configuration ESXi main server

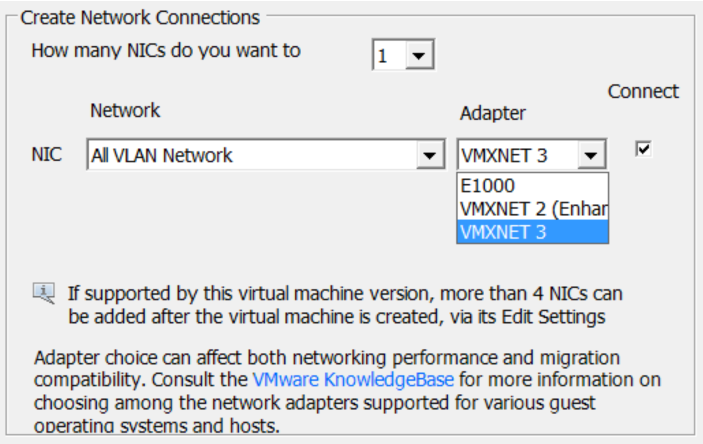
Fig. 3.3 shows the virtual network configuration of 1vSphere on the main server. As displayed, two physical network adapters are assigned to vSwitch0 in order to achieve redundancy and load balancing, as described in the previous chapter. Every network adapter works at 1 Gbps full duplex.
Due to the trunk, that has been configured on core switch 1, VLAN tagging has to be done on the vSphere too, in order to identify the different VLANs and successfully split the packets. For example core switch 1 is now tagging all packets that correspond to VLAN 10 with a 802.1Q tag containing the label 10. Only by doing this, the opposite side is then able to identify packets that belong to VLAN 10 by looking at the 802.1Q tag in the header of the IP packet.
For example the port group "Management Network", that can be seen in the picture, only handles packets with a 802.1Q tag that contain the VLAN ID 10.

In general two different connection types are distinguished. The VMKernel Port and the Virtual Machine Port Group. The former is a TCP/IP stack to manage traffic for

the ESXi services vSphere Motion, iSCSI, NFS and host management. The latter is a virtual network interface that mainly offers three different options: define a specific VLAN ID, allow all VLAN IDs or allow no VLAN ID.
When a VLAN ID is specified on the virtual network interface only packets belonging to that VLAN are processed. Moreover the 802.1Q tag gets removed from the packet header.
When the virtual network interface is configured to allow all VLAN IDs, every packet containing a 802.1Q tag is processed. Therefore the operating system must take care of the separation of the packets concerning the VLANs.
If the virtual network interface is configured for no VLAN ID, only untagged packets will get processed by that interface.

The "ESX Network" of type VMkernel Port, as shown in the figure, is used to process the management traffic for the ESXi host. Only this VMkernel Port has an IP address assigned. The ESXi host is accessible via this configured IP address.
On the backup server this network was additionally used to access the iSCSI Target that is located on the NAS.

As seen in the figure the VMs "dc", "fs", "sw" and "backup" are assigned to the "All VLAN Network". That means that the VLAN separation has to be done within the operating system. In order to be able to use that, the network adapter for the VM has to be of the VMXNET3, as seen in figure 3.4.



Create Network Connections

How many NICs do you want to: 1

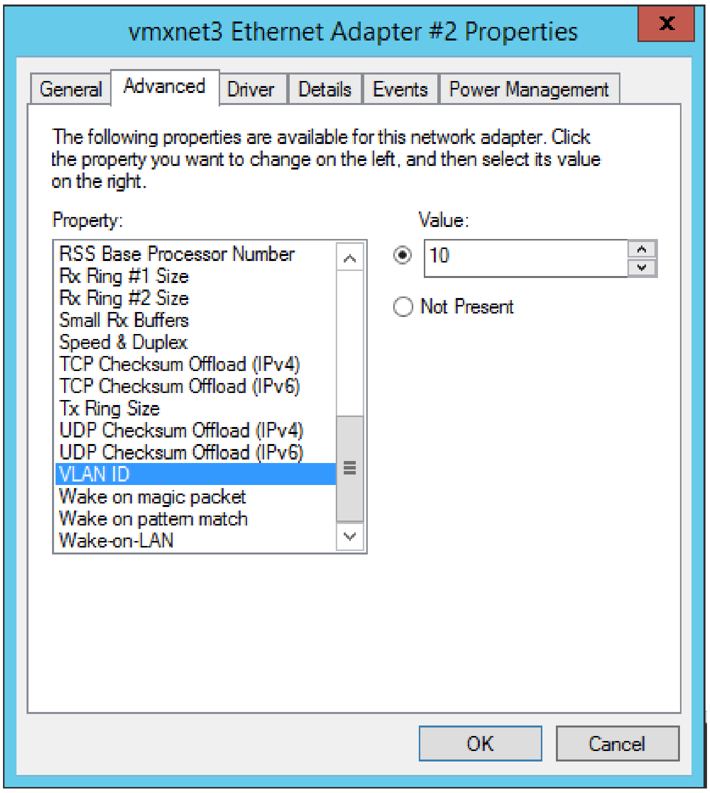
	Network	Adapter	Connect
NIC	All VLAN Network	VMXNET 3	☑

If supported by this virtual machine version, more than 4 NICs can be added after the virtual machine is created, via its Edit Settings

Adapter choice can affect both networking performance and migration compatibility. Consult the VMware KnowledgeBase for more information on choosing among the network adapters supported for various guest operating systems and hosts.

Figure 3.4: Network adapter VMXNET3

After using VMXNET3 as network adapter type and allowing "All VLANs" on the network, the VLAN can be configured within the properties of the specific NIC on the operating system. Fig. 3.5 shows the procedure in case of a Windows Server 2012 R2.



The following properties are available for this network adapter. Click the property you want to change on the left, and then select its value on the right.

Property:

RSS Base Processor Number
Rx Ring #1 Size
Rx Ring #2 Size
Small Rx Buffers
Speed & Duplex
TCP Checksum Offload (IPv4)
TCP Checksum Offload (IPv6)
Tx Ring Size
UDP Checksum Offload (IPv4)
UDP Checksum Offload (IPv6)
VLAN ID
Wake on magic packet
Wake on pattern match
Wake-on-LAN

Value:

● 10

○ Not Present

Figure 3.5: Configuring VLAN ID on NIC

The WAN interface of the VM "firewall" was connected to a network with the VLAN ID 5 and the LAN interface also the network with all VLANs allowed.

The debian based VM "monitoring" was connected to a network for VLAN 10, because only one VLAN was needed and thus no VLAN configuration within the operating system had to be made.

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