Welcome to

Networking and TCP/IP for Beginners

BornHack July 2024

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Slides are available as PDF, kramse@Codeberg

basic-tcpip.tex in the repo security-courses

Contact information

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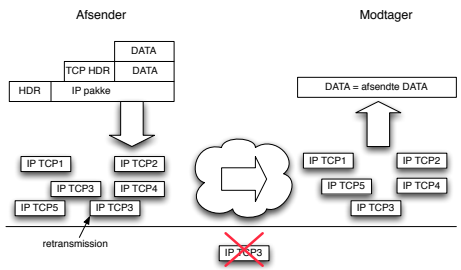
- Run a small network for fun AS57860

You are welcome to drop me an email

Goals for today



- Introduce basic TCP/IP terminology
- Show the BornHack network
- Describe how you can connect a router or switch to the network
- Describe basics of TCP/IP in 60-75 minutes
- Let you get some hands on with IP protocols

Photo is NWWC camp at BornHack 2024, come by and say hi

Time schedule

- 15:00 - 15:45
  Introduction and basics
- 15:45 - 17:00
  Connect to the network, play with TCP/IP, switches and routers.

Note: even though I talk a lot about Unix and Linux, you can definitely run a lot of tools on Windows and Mac OS X. The basic tools are available like the built-in ones and Nmap

Command line tools are sometimes used in the slides, as they only show text where a GUI screenshot can be cluttered with a lot of information, feel free to find GUI tools and web sites with same functionality

Exercises

Exercises are completely optional

- Try ping and traceroute
- See your own IP settings
- Borrow a USB Ethernet and connect to a switch or router

Linux is a toolbox I will use and participants are recommended to research virtual machines

Course Materials

- This material is in multiple parts:
- Slide show - presentation - this file
- Exercises - PDF which is used for this and other workshops
- Additional resources from the internet are linked throughout
- Wikipedia has a LOT of nice pages about IP protocols, for example:

> Transport Layer Security (TLS) is a cryptographic protocol designed to provide communications security over a computer network. The protocol is widely used in applications such as email, instant messaging, and voice over IP, but its use in securing HTTPS remains the most publicly visible.

Source: https://en.wikipedia.org/wiki/Transport_Layer_Security

Prerequisites

If you are interested in TCP/IP you are welcome

If you want to be an expert in IP and network security I recommend doing exercises

It is recommended to use virtual machines for the exercises

Network security and most internet related security work has the following requirements:

- Network experience
- TCP/IP principles - often in more detail than a common user
- Programming is an advantage, for automating things
- Some Linux and Unix knowledge is in my opinion a **necessary skill** for infosec work
  – too many new tools to ignore, and lots found at sites like Github and Open Source written for Linux

Wifi Hardware

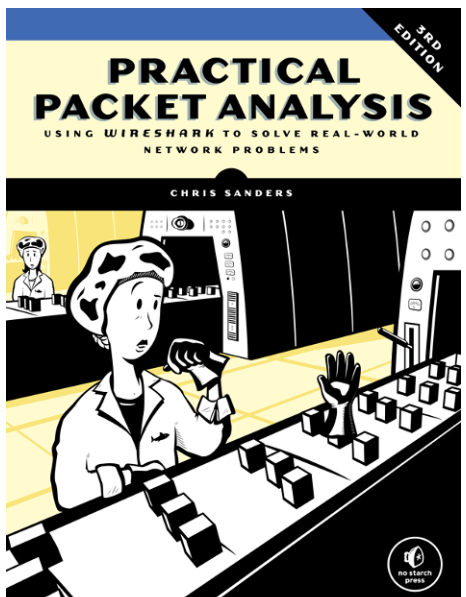
If you want to do sniffing of wireless it will be an advantage to have a wireless USB network card. Make sure to play nice, and dont abuse knowledge!

- The following are two recommended models:
- TP-link TL-WN722N hardware version 2.0 cheap but only support 2.4GHz
- Alfa AWUS036ACH 2.4GHz + 5GHz Dual-Band and high performing
- Both work great in Kali Linux for our purposes, but are older models by now

Unfortunately the vendors change models often enough that the above are hard to find. I recommend using your favourite search engine and research which cards work with Kali Linux and airodump-ng.

I have some available you can borrow

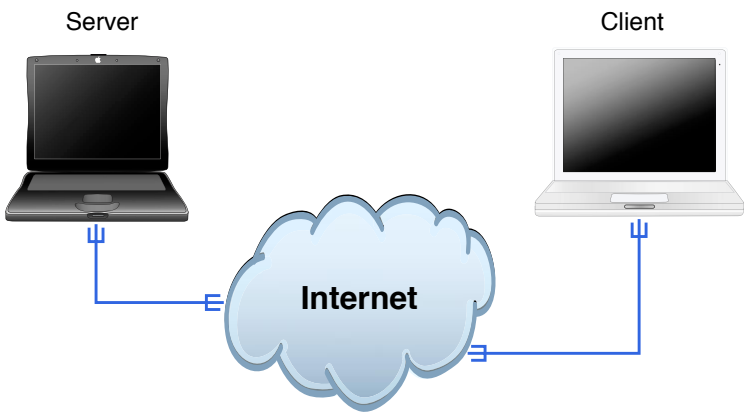
Book: Practical Packet Analysis (PPA)



Practical Packet Analysis, Using Wireshark to Solve Real-World Network Problems by Chris Sanders, 3rd Edition April 2017, 368 pp. ISBN-13: 978-1-59327-802-1 https://nostarch.com/packetanalysis3

I recommend this book for people new to networking, it has been in HumbleBundle book bundles multiple times

Internet Today



Clients and servers, roots in the academic world

Protocols are old, some more than 20 years

Very few protocols where encrypted, today a lot has switched to HTTPS and TLS

Internet is Open Standards!

We reject kings, presidents, and voting.
We believe in rough consensus and running code.
– The IETF credo Dave Clark, 1992.

Request for comments (RFC) – a series of documents spanning decades

RFC, BCP, FYI, informational – first ones from 1969!

Are not updated but status is changed to Obsoleted when new versions are published

Standards track:
Proposed Standard $\rightarrow$ Draft Standard $\rightarrow$ Standard

Internetworking: history

1961 L. Kleinrock, MIT packet-switching theory
1962 J. C. R. Licklider, MIT - notes
1964 Paul Baran: On Distributed Communications
1969 ARPANET 4 nodes
1971 14 nodes
1973 Design of Internet Protocols started
1973 Email is about 75% of all ARPANET traffic
1974 TCP/IP: Cerf/Kahn: A protocol for Packet Network Interconnection
1983 EUUG $\rightarrow$ DKUUG/DIKU Denmark
1988 About 60.000 systems on the internet - The Morris Worm hits about 10%
2002 About 130 million Internet hosts
2010 IANA reserved blocks 7% (Maj 2010) - http://www.potaroo.net/tools/ipv4/

What is the Internet

Communication between humans - currently!

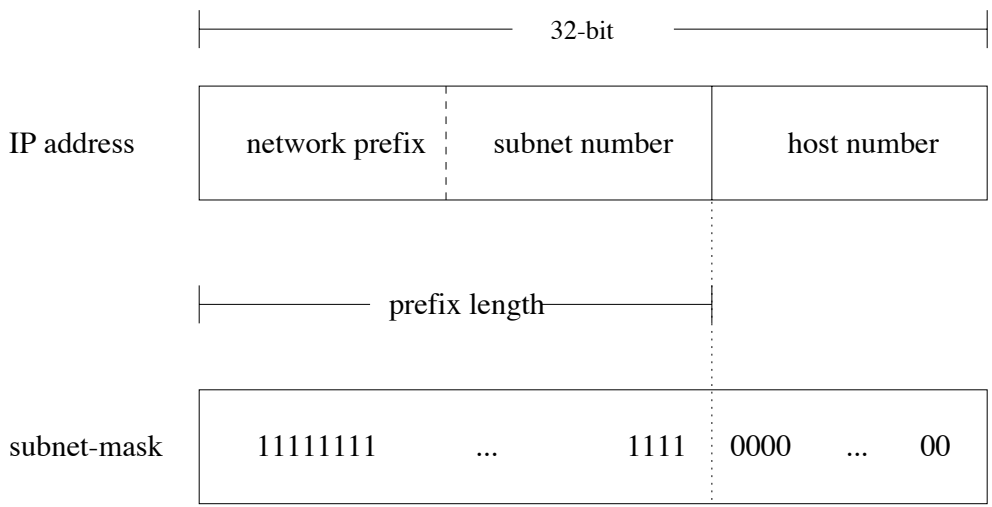
Based on TCP/IP

- best effort
- packet switching (IPv6 calls it packets, not datagram)
- *connection-oriented* TCP
- *connection-less* UDP

RFC-1958:

> A good analogy for the development of the Internet is that of constantly renewing the individual streets and buildings of a city, rather than razing the city and rebuilding it. The architectural principles therefore aim to provide a framework for creating cooperation and standards, as a small "spanning set"of rules that generates a large, varied and evolving space of technology.

Common Address Space



- Internet is defined by the address space
- IPv4 based on 32-bit addresses, example dotted decimal format 10.0.0.1
- IPv6 very similar to IPv4 without NAT, 128-bit addresses in hex ::1, 2a06:d380:0:101::80

How to use the Internet Protocols (IP)

Names are used by humans

www.kramse.org

hlk@kramse.org

Computers use the addresses

```
www     IN      A       185.129.63.130
        IN      AAAA    2a06:d380:0:102::80
mail    IN      A       217.157.63.115
        IN      AAAA    2a06:d380:0:102::25
```

Documentation Prefix, IPv6 updates etc.

Even documentation has its own prefix, RFC5737:

```
The blocks 192.0.2.0/24 (TEST-NET-1), 198.51.100.0/24 (TEST-NET-2),
and 203.0.113.0/24 (TEST-NET-3) are provided for use in
documentation.
```

IPv6 listed in RFC3849 `2001:DB8::/32`

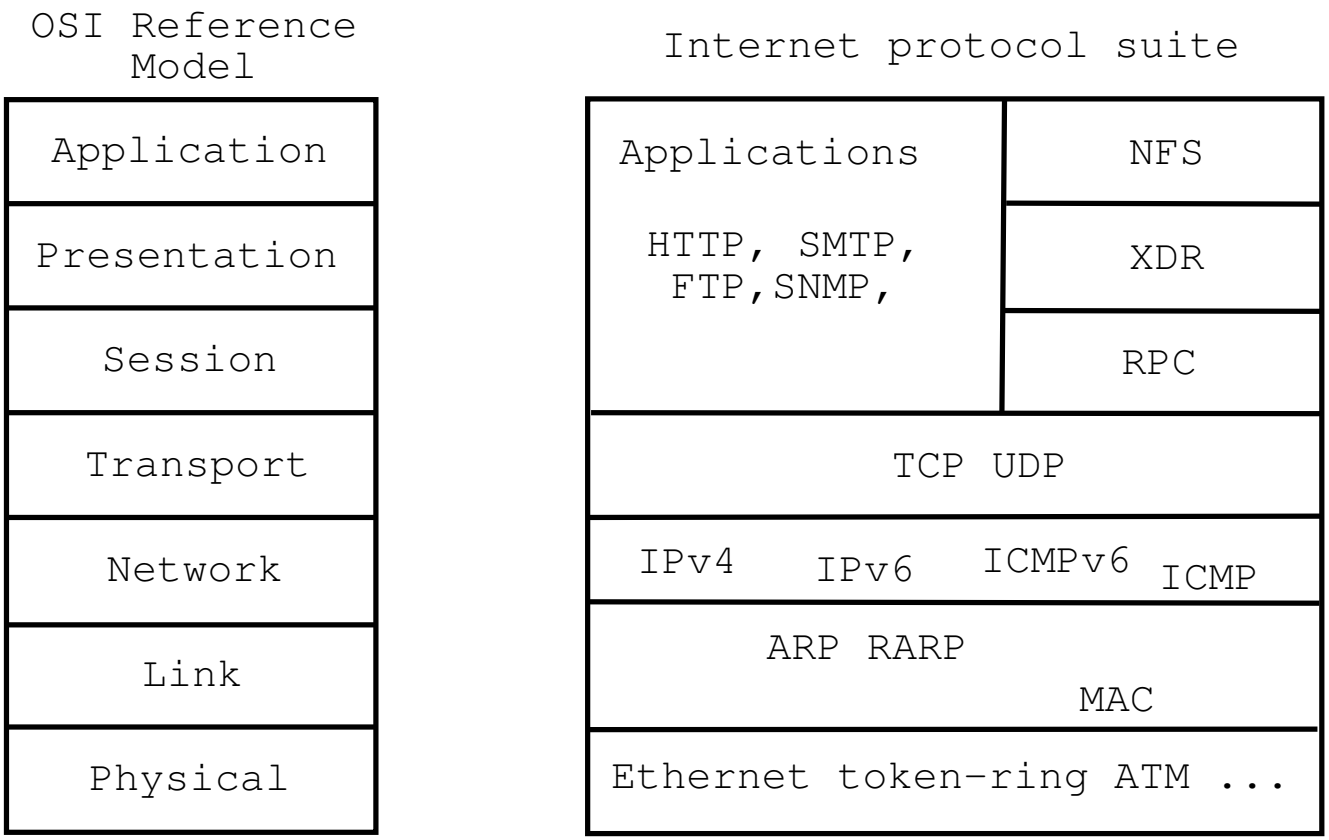
See RFC3330 *Special-Use IPv4 Addresses* which is updated by RFC6890 *Special-Purpose IP Address Registries* which in turn is updated by RFC8190
Use the web version of RFCs to surf back and forth https://www.rfc-editor.org/rfc/rfc8190

CIDR Classless Inter-Domain Routing

Classful routing		Classless routing CIDR	
4 class C networks	Inherent subnet mask	Supernet	Subnet mask
192.0.8.0	255.255.255.0	192.0.8.0	255.255.252.0
192.0.9.0	255.255.255.0		252d=11111100b
192.0.10.0	255.255.255.0		
192.0.11.0	255.255.255.0	Base network/prefix	
		192.10.8.0/22	

- Subnet mask originally inferred by the class
- Started to allocate multiple C-class networks - save remaining B-class
  Resulted in routing table explosion - btw Stop using A, B, C
- A subnet mask today is a row of 1-bit
- Supernet, supernetting
- 10.0.0.0/24 means the network 10.0.0.0 with 24 subnet bits (mask 255.255.255.0)
- 2a06:d380:0:101::80/64 means the network with 64-bit prefix length

Protocols: OSI and Internet models



Ethernet, cables

Show link, and activity – blinkenlights

MAC address

```
00-03-93    (hex)        Apple Computer, Inc.
000393      (base 16)    Apple Computer, Inc.
                         20650 Valley Green Dr.
                         Cupertino CA 95014
                         UNITED STATES
```

Network technologies use a layer 2 hardware address

Typically using 48-bit MAC addresses known from Ethernet MAC-48/EUI-48

First half is assigned to companies – Organizationally Unique Identifier (OUI)

Using the OUI you can see which producer and roughly when a network chip was produced

http://standards.ieee.org/regauth/oui/index.shtml

Bridges

Ethernet is a broadcast technology data transmitted into the ether – a cable

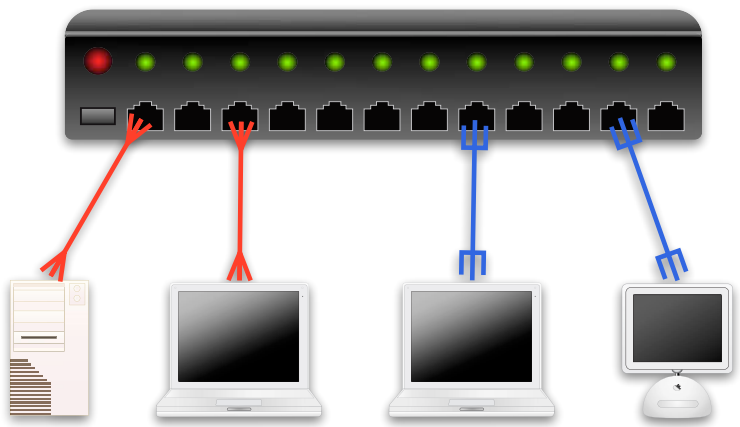
This limits how many devices to connect

Using bridges we can connect segments – which copy between them if needed

It learns the devices on each side (MAC address)

See also http://en.wikipedia.org/wiki/ALOHAnet

A switch



Today we use switches, Don't buy a hub, not even for experimenting or sniffing

A switch can receive and send data on multiple ports at the same time

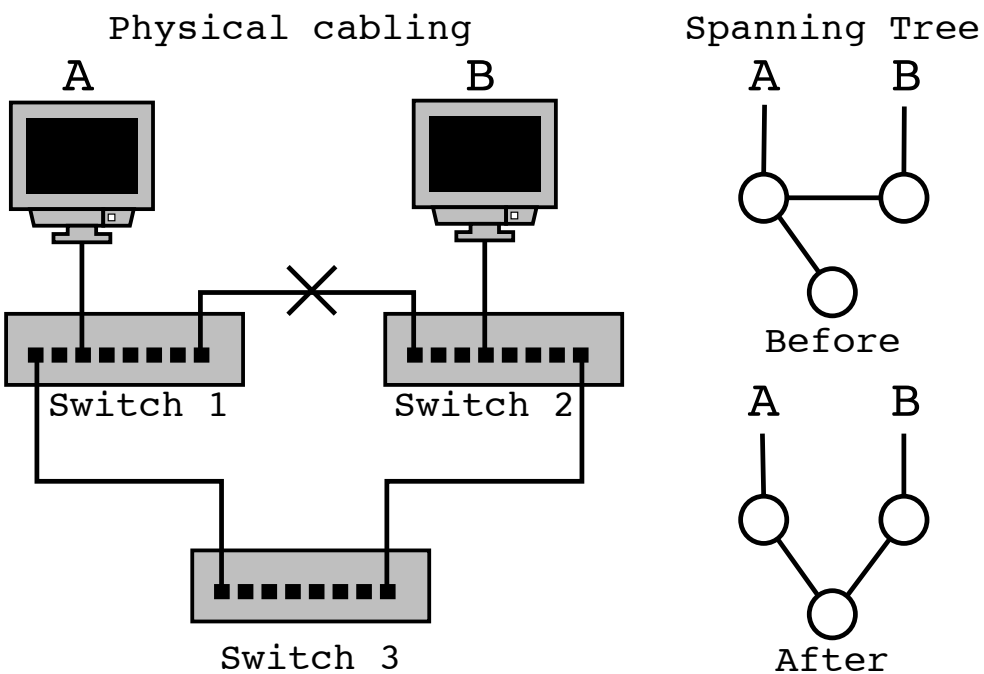
Performance only limited by the backplane and switching chips

Can also often route with the same speed and mirror packets

Wireless

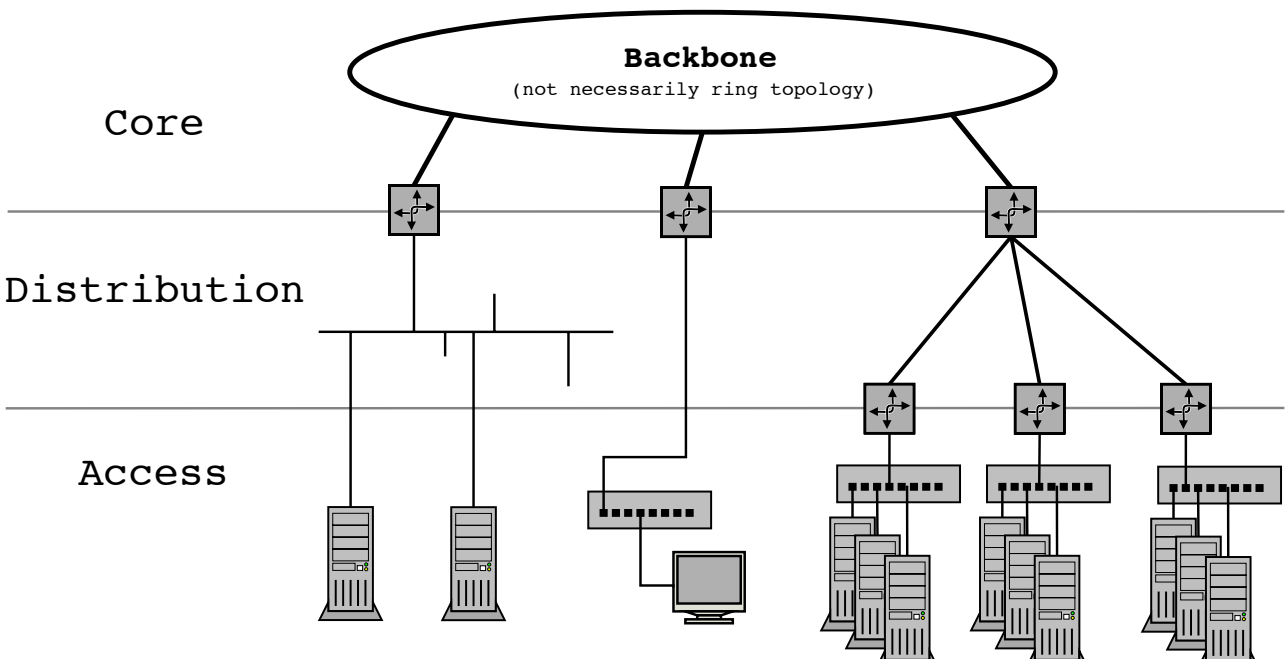
A typical home router would have built-in 802.11 Access-Point (AP) and some Ethernet LAN ports

Topologier og Spanning Tree Protocol



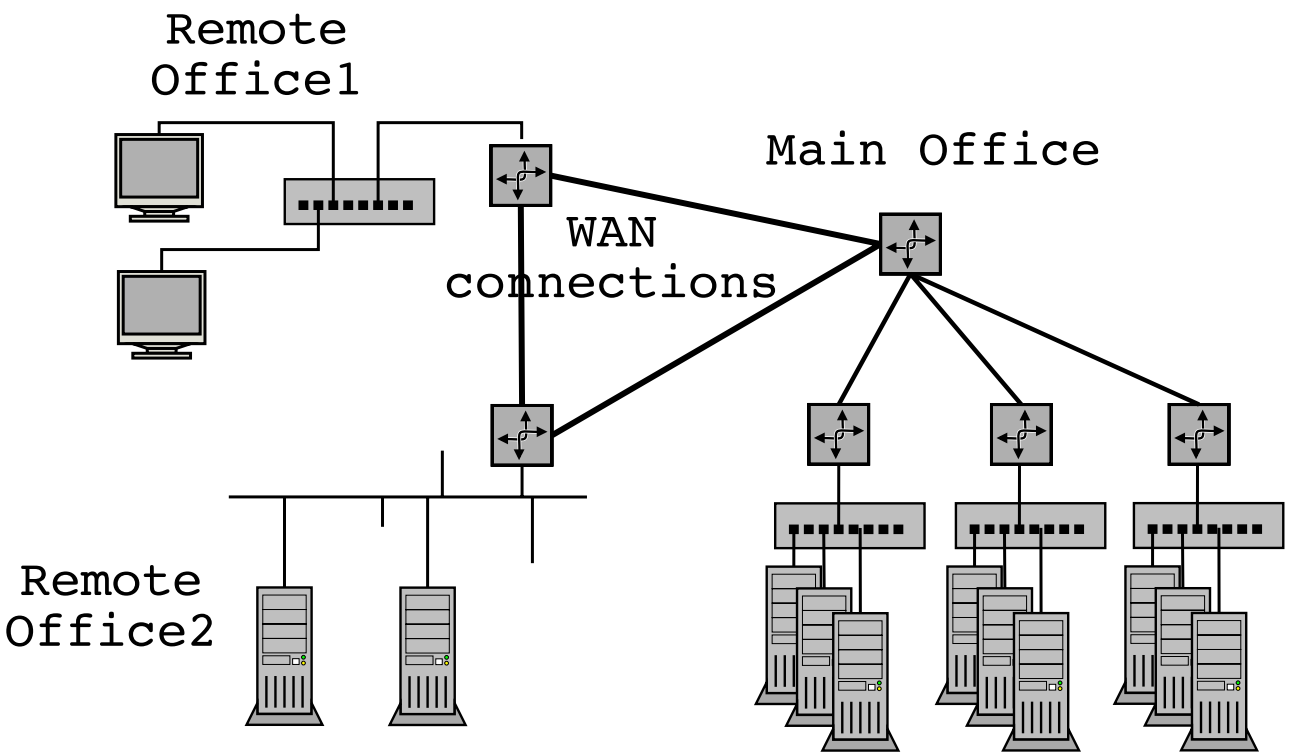
Se mere i bogen af Radia Perlman, *Interconnections: Bridges, Routers, Switches, and Internetworking Protocols*

Core, Distribution og Access net

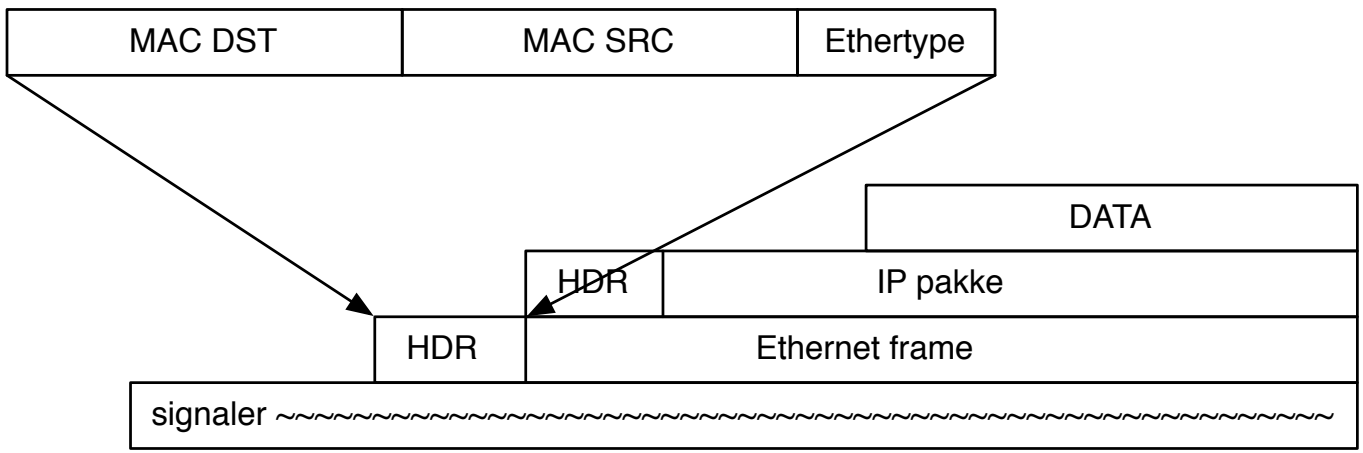


Det er ikke altid man har præcis denne opdeling, men den er ofte brugt

Bridges and routers



Packets of data

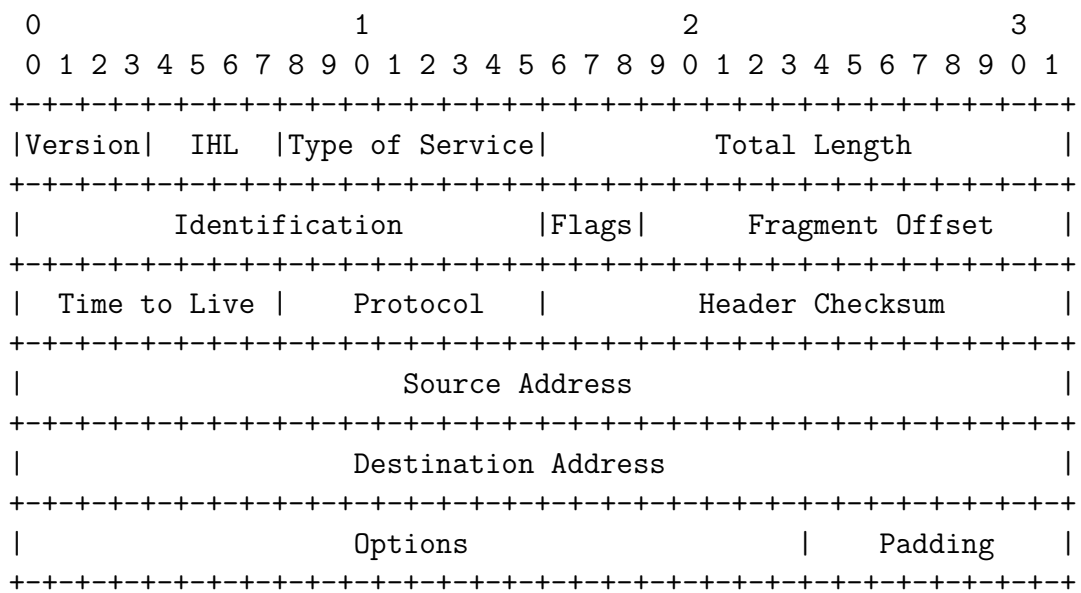


Looking into the hardware we see that data is laid out according to a structure – frames and packets

Often a start and end signal of a frame – like Ethernet

Today we talk about packets of 1500 bytes which is common in Ethernet

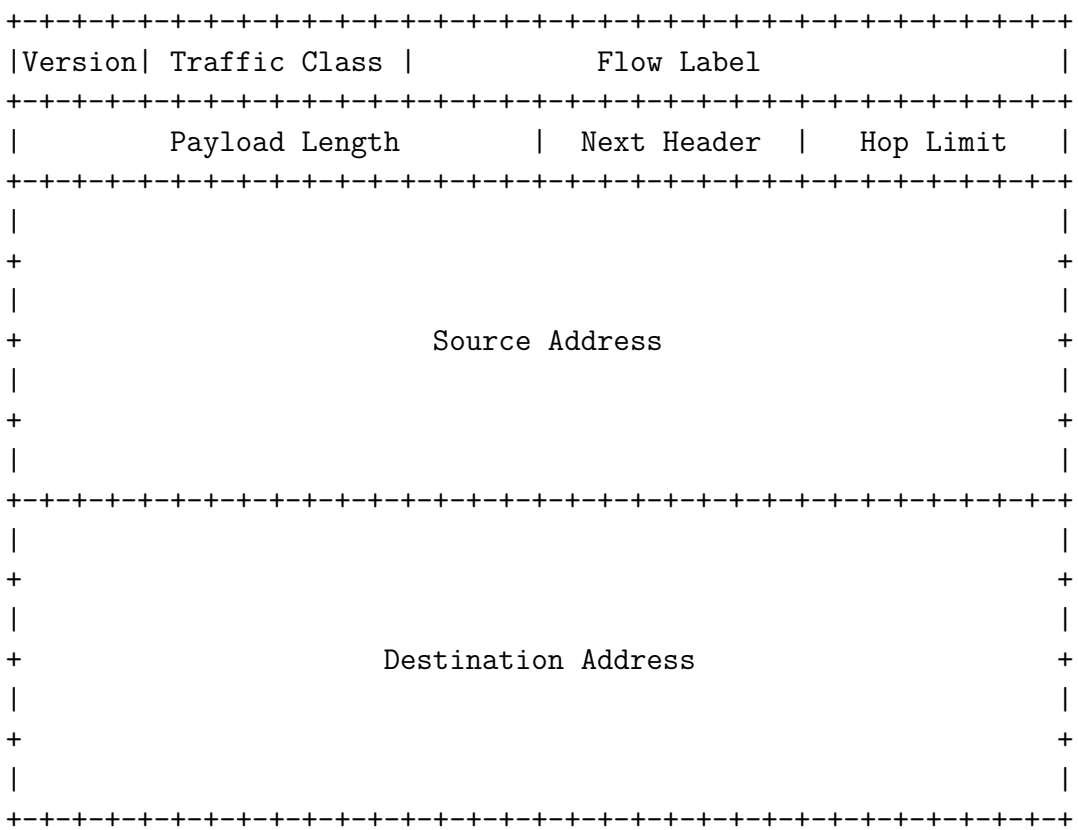
IPv4 header - RFC-791 september 1981



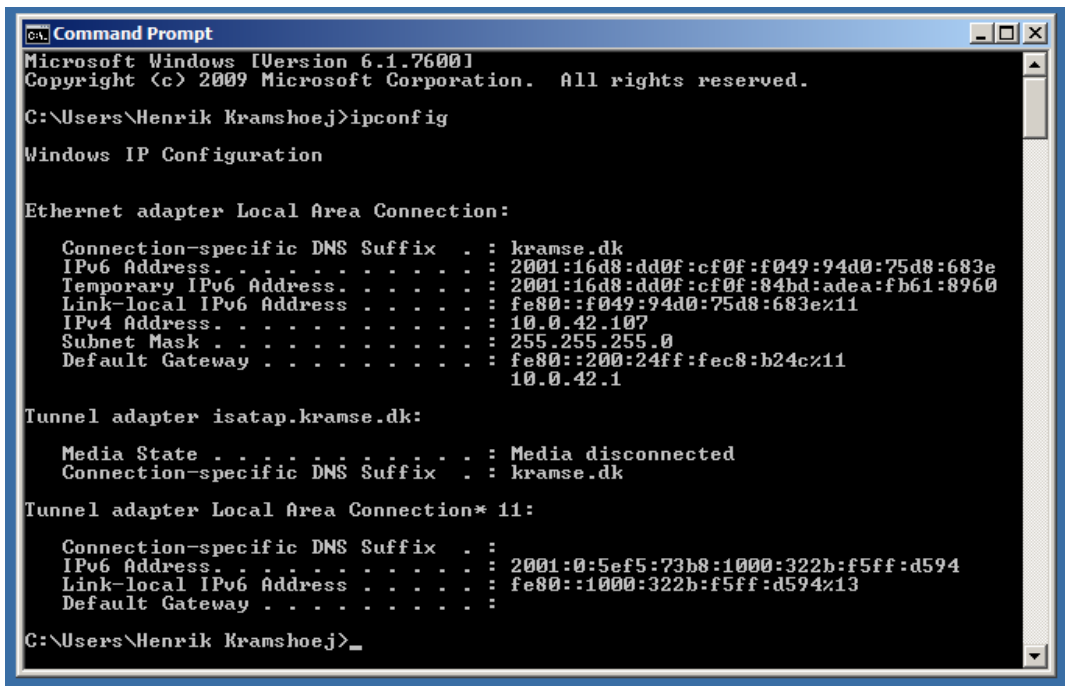
Example Internet Datagram Header

Source: https://datatracker.ietf.org/doc/html/rfc791 and updated later

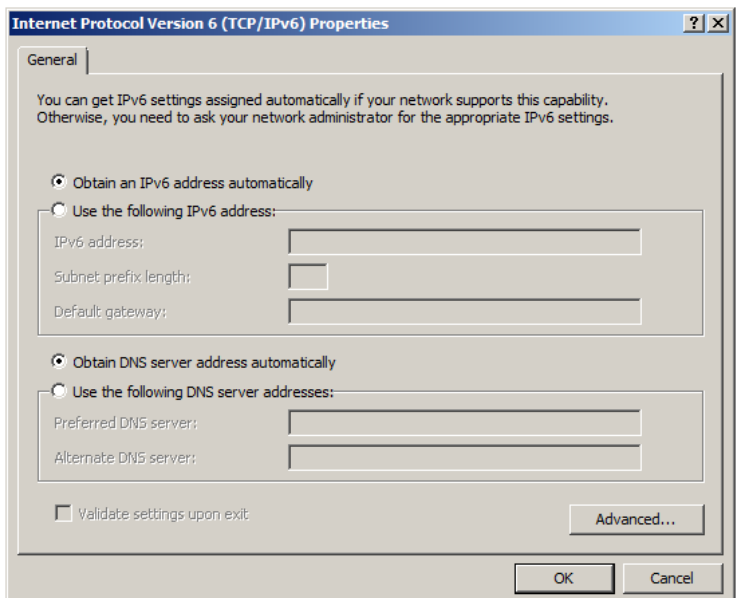
IPv6 header - RFC-1883 December 1995



Windows - ipconfig



Windows – control panel with DHCP



DHCP is responsible for giving you a dynamic address

Unix - practical examples ifconfig and ping

```
$ ifconfig en0
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
        inet6  fe80::216:cbff:feac:1d9f%en0 prefixlen 64 scopeid 0x4
        inet  10.0.42.15 netmask 0xffffff00 broadcast 10.0.42.255
        inet6  2001:16d8:dd0f:cf0f:216:cbff:feac:1d9f prefixlen 64 autoconf
        ether 00:16:cb:ac:1d:9f
        media: autoselect (1000baseT <full-duplex>) status: active

$ ping6 ::1
PING6(56=40+8+8 bytes) ::1 --> ::1
16 bytes from ::1, icmp_seq=0 hlim=64 time=0.089 ms
16 bytes from ::1, icmp_seq=1 hlim=64 time=0.155 ms

$ traceroute6 2001:16d8:dd0f:cf0f::1
traceroute6 to 2001:16d8:dd0f:cf0f::1 (2001:16d8:dd0f:cf0f::1)
from 2001:16d8:dd0f:cf0f:216:cbff:feac:1d9f, 64 hops max, 12 byte packets
 1  2001:16d8:dd0f:cf0f::1  0.399 ms  0.371 ms  0.294 ms
```

Knowledge and insight

- Networks have end-points and conversations on multiple layers
- Wireshark is advanced, try right-clicking different places
- Name resolution includes low level MAC addresses, and IP - names

- Tcpdump format, built-in to many network devices
- Remote packet dumps, like `tcpdump -i eth0 -w packets.pcap`
- Story: tcpdump was originally written in 1988 by Van Jacobson, Sally Floyd, Vern Paxson and Steven McCanne who were, at the time, working in the Lawrence Berkeley Laboratory Network Research Group https://en.wikipedia.org/wiki/Tcpdump

Great network security comes from knowing networks!

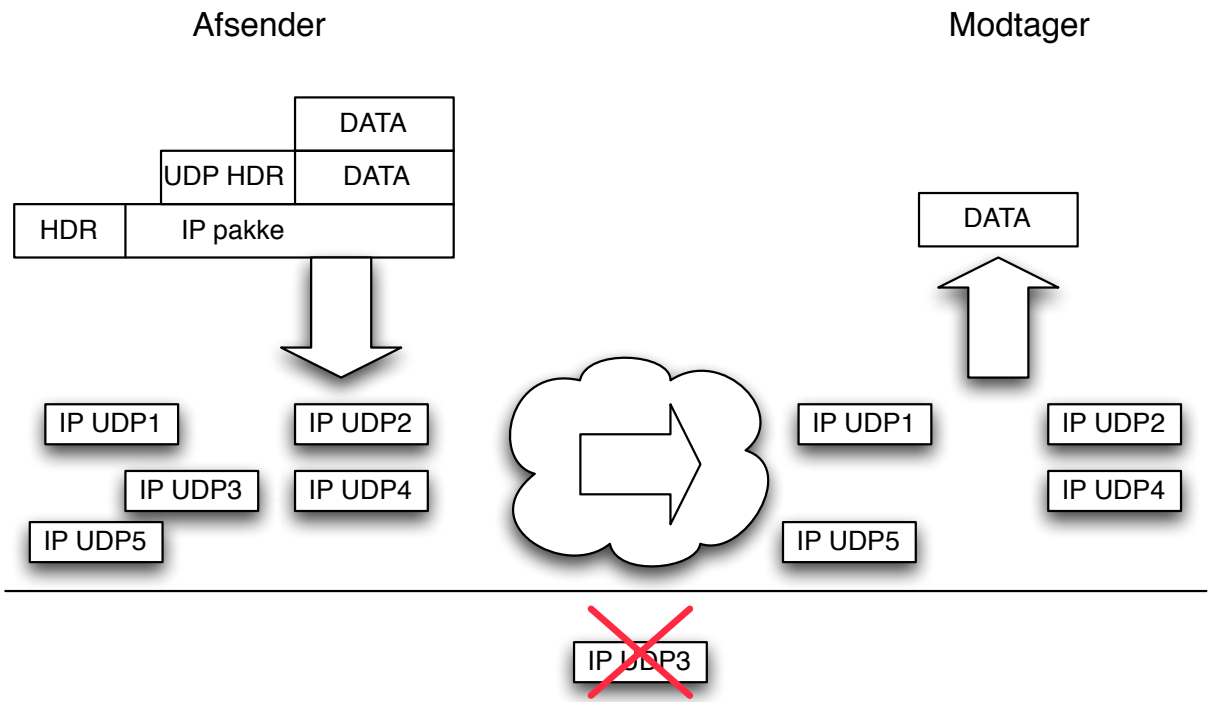
Network Knowledge Needed

To work with network security the following protocols are the bare minimum to know about.

- ARP Address Resolution Protocol for IPv4
- NDP Neighbor Discovery Protocol for IPv6
- IPv4 & IPv6 – the basic packet fields source, destination,
- ICMPv4 & ICMPv6 Internet Control Message Protocol
- UDP User Datagram Protocol
- TCP Transmission Control Protocol
- DHCP Dynamic Host Configuration Protocol
- DNS Domain Name System

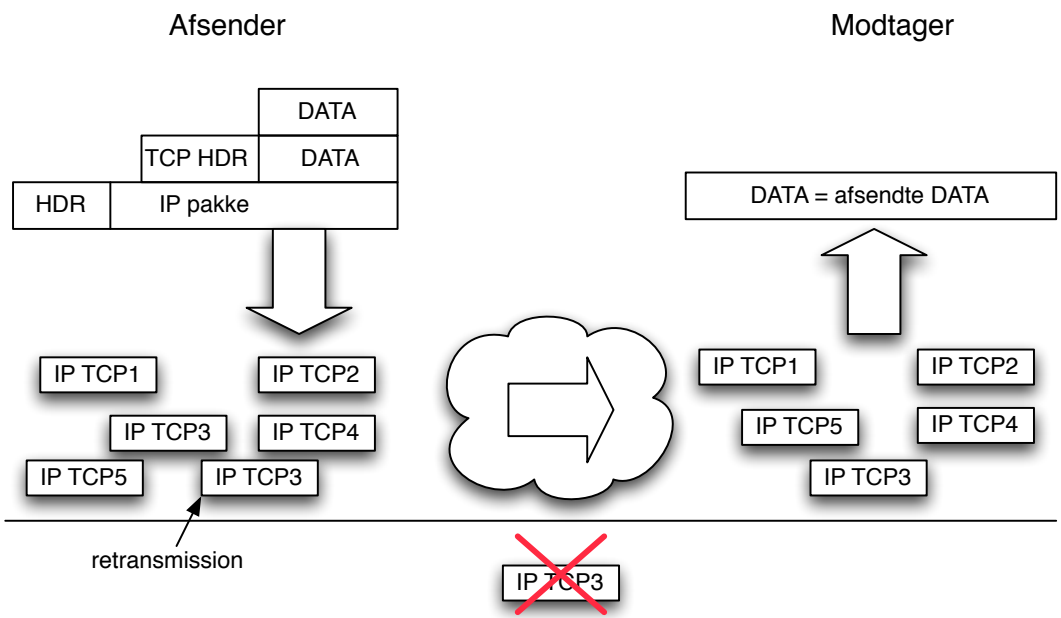
A little Linux knowledge is also **highly recommended**

UDP User Datagram Protocol



Connectionless https://en.wikipedia.org/wiki/User_Datagram_Protocol

TCP Transmission Control Protocol



Connection-oriented https://en.wikipedia.org/wiki/Transmission_Control_Protocol

Well-Known Port Numbers

IANA maintains a list of magical numbers in TCP/IP

Lists of protocl numbers, port numers etc.

A few notable examples:

- Port 25/tcp Simple Mail Transfer Protocol (SMTP)
- Port 53/udp and 53/tcp Domain Name System (DNS)
- Port 80/tcp Hyper Text Transfer Protocol (HTTP)
- Port 443/tcp HTTP over TLS/SSL (HTTPS)

Source: http://www.iana.org

Whois – Where do IP addresses come from

A these magical numbers we use on the internet are administered by IANA https://www.iana.org/

They have handed out portions to the Region Internet Registries (RIR)

- RIPE (Réseaux IP Européens) http://ripe.net
- ARIN American Registry for Internet Numbers http://www.arin.net
- Asia Pacific Network Information Center http://www.apnic.net
- LACNIC (Regional Latin-American and Caribbean IP Address Registry) - Latin America and some Caribbean Islands

AFRINIC https://afrinic.net/

They are memberbased, and members are called Local Internet Registries (LIRs) og National Internet Registry (NIR)

Ping

ICMP - Internet Control Message Protocol

Benyttes til fejlbeskeder og til diagnosticering af forbindelser

ping programmet virker ved hjælp af ICMP ECHO request og forventer ICMP ECHO reply

```
$ ping 192.168.1.1
PING 192.168.1.1 (192.168.1.1): 56 data bytes
64 bytes from 192.168.1.1: icmp_seq=0 ttl=150 time=8.849 ms
64 bytes from 192.168.1.1: icmp_seq=1 ttl=150 time=0.588 ms
64 bytes from 192.168.1.1: icmp_seq=2 ttl=150 time=0.553 ms
```

traceroute

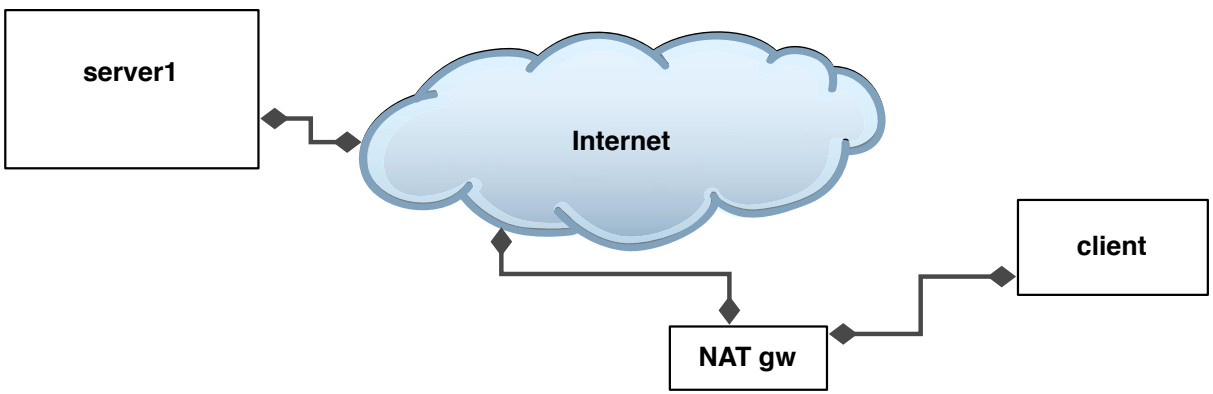
traceroute programmet virker ved hjælp af TTL

levetiden for en pakke tælles ned i hver router på vejen og ved at sætte denne lavt opnår man at pakken *timer ud* - besked fra hver router på vejen

default er UDP pakker, men på UNIX systemer er der ofte mulighed for at bruge ICMP

```
$ traceroute 185.129.60.129
traceroute to 185.129.60.129 (185.129.60.129),
30 hops max, 40 byte packets
 1  safri (10.0.0.11)  3.577 ms  0.565 ms  0.323 ms
 2  router (185.129.60.129)  1.481 ms  1.374 ms  1.261 ms
```

NAT Network Address Translation



- NAT is used for connecting private networks to the Internet
- NAT gateway replaces source address and forwards packets
- A quick and dirty fix that keeps messing up networks and protocols
- The NAT router/firewall has state tables

RFC-1918 Private Networks

There is a list of network prefixes anyone can use, for private networks:

- 10.0.0.0 - 10.255.255.255 (10/8 prefix)
- 172.16.0.0 - 172.31.255.255 (172.16/12 prefix)
- 192.168.0.0 - 192.168.255.255 (192.168/16 prefix)

Address Allocation for Private Internets RFC-1918 adresserne!

To use these typically there will be a NAT device in front

```
The blocks 192.0.2.0/24 (TEST-NET-1), 198.51.100.0/24 (TEST-NET-2),
and 203.0.113.0/24 (TEST-NET-3) are provided for use in
documentation.

169.254.0.0/16 has been ear-marked as the IP range to use for end node
auto-configuration when a DHCP server may not be found
```

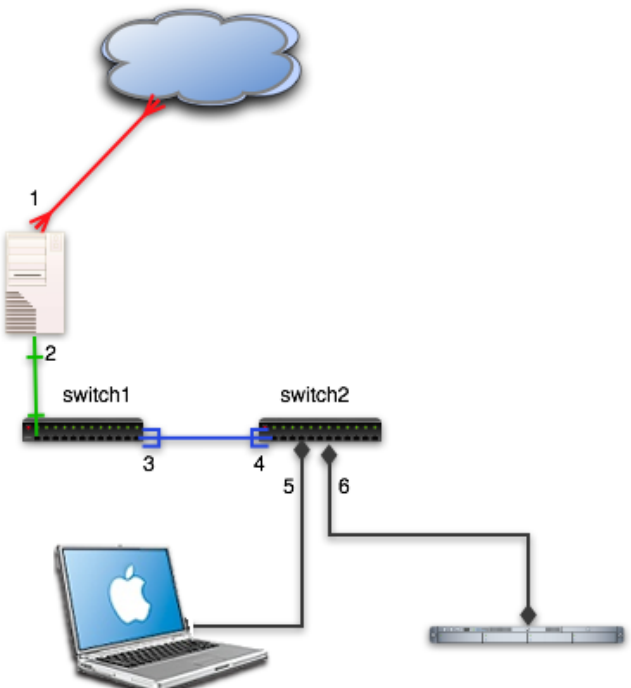
Course Network

.

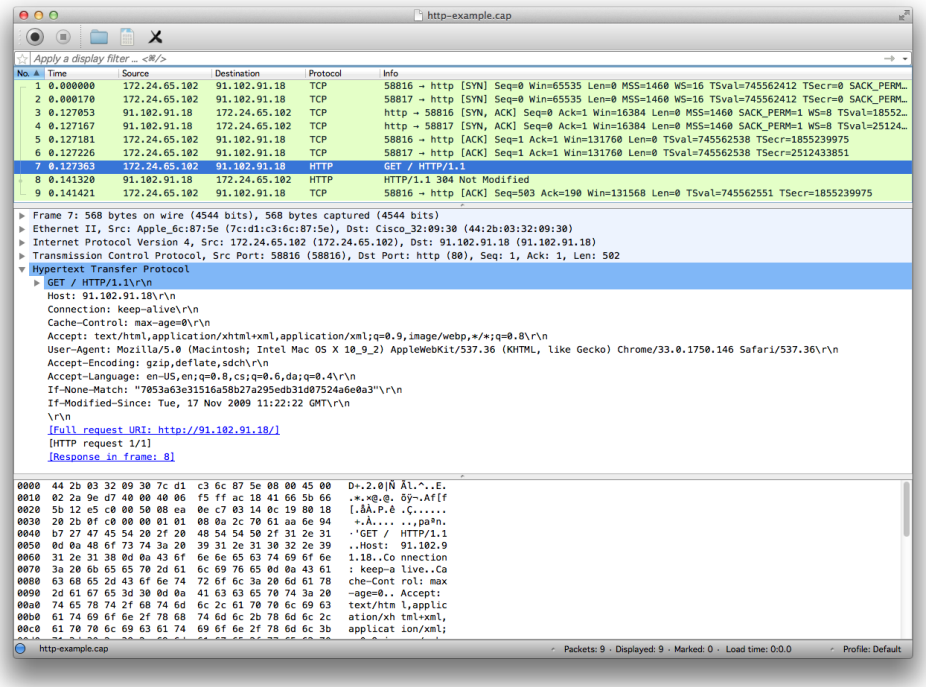
I have a course network with me – the whole of BornHack ☺ which has the following information:

- Juniper MX240 router – in the basement, we can go see it
- Juniper switches
- Aruba APs wireless access-points
- IPv4 addresses: 151.216.32.0/21 total 2048
- IPv6 addresses route6: 2001:678:9ec::/48
- Autonomous system number: AS208647 BornHack
  https://en.wikipedia.org/wiki/Autonomous_system_(Internet)

You are encouraged to use the network



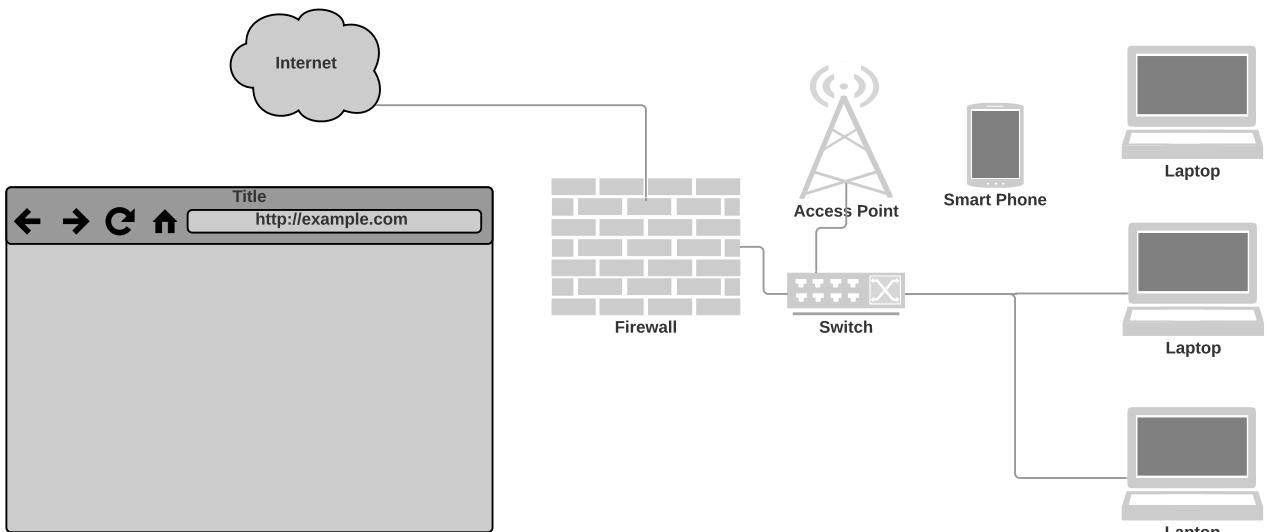
Wireshark - graphical network sniffer



Capture - Options, select a network interface

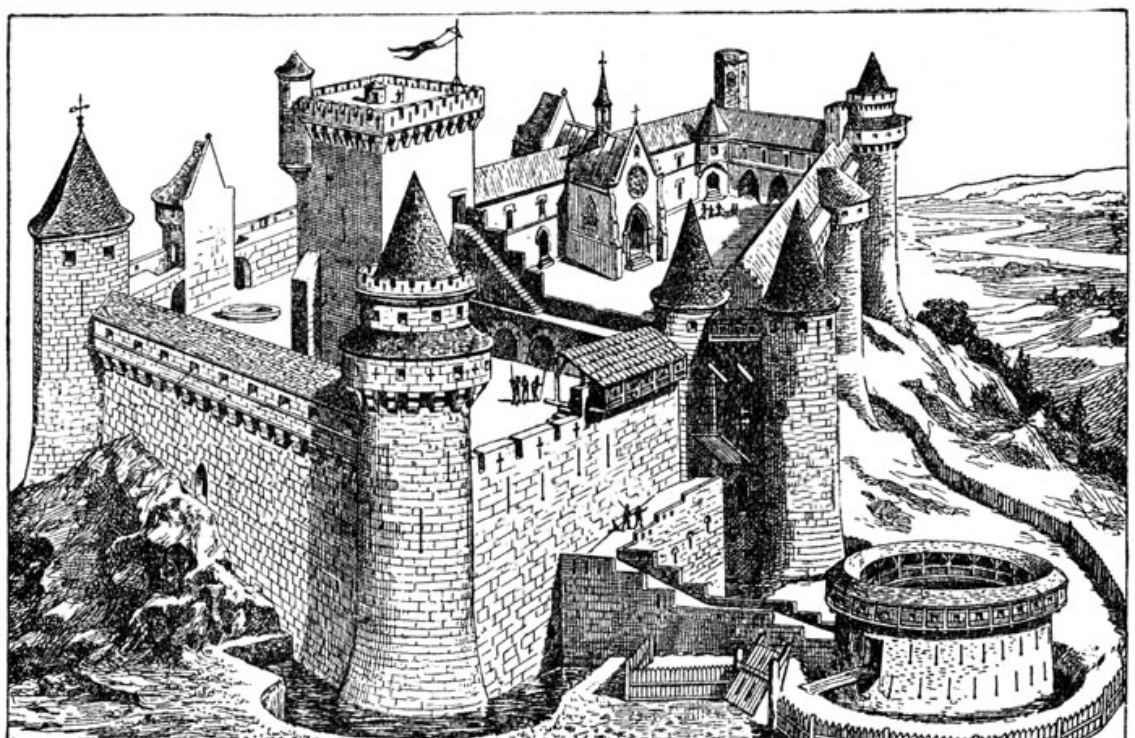
http://www.wireshark.org

Your Privacy



- Your data travels far
- Often crossing borders, virtually and literally

Defense in depth



Picture originally from: http://karenswhimsy.com/public-domain-images

Network Segmentation – Firewalls

$ firewall

1. (I) **An internetwork gateway that restricts data communication traffic to and from one of the connected networks** (the one said to be "inside"the firewall) and thus protects that network's system resources against threats from the other network (the one that is said to be "outside"the firewall). (See: guard, security gateway.)
2. (O) **A device or system that controls the flow of traffic between networks using differing security postures.** Wack, J. et al (NIST), "Guidelines on Firewalls and Firewall Policy", Special Publication 800-41, January 2002.

Tutorial: A firewall typically protects a smaller, secure network (such as a corporate LAN, or even just one host) from a larger network (such as the Internet). The firewall is installed at the point where the networks connect, and the firewall applies policy rules to control traffic that flows in and out of the protected network.

Source: RFC4949 *Internet Security Glossary, Version 2*

https://datatracker.ietf.org/doc/html/rfc4949 2007

Continued

> **A firewall is not always a single computer.** For example, a firewall may consist of a pair of filtering routers and one or more proxy servers running on one or more bastion hosts, all connected to a small, dedicated LAN (see: buffer zone) between the two routers. The external router blocks attacks that use IP to break security (IP address spoofing, source routing, packet fragments), while proxy servers block attacks that would exploit a vulnerability in a higher-layer protocol or service. The internal router blocks traffic from leaving the protected network except through the proxy servers. The difficult part is defining criteria by which packets are denied passage through the firewall, because a firewall not only needs to keep unauthorized traffic (i.e., intruders) out, but usually also needs to let authorized traffic pass both in and out.

Source: RFC4949 *Internet Security Glossary, Version 2*

https://datatracker.ietf.org/doc/html/rfc4949 2007

- Network layer, packet filters, application level, stateless, stateful
- Firewalls are by design a choke point, natural place
  to do network security monitoring!
- Older but still interesting Cheswick chapter 2 PDF *A Security Review of Protocols: Lower Layers*
  http://www.wilyhacker.com/

Modern Firewall Infrastructures

A firewall blocks traffic on a network

A firewall allows traffic on a network

The interesting part is typically what it allows!

A firewall infrastructure must:

- Prevent attackers from entering
- Prevent data exfiltration
- Prevent worms, malware, virus from spreading in networks
- Be part of an overall solution with ISP, routers, other firewalls, switched infrastructures, intrusion detection systems and the rest of the infrastructure
- ...

Difficult – and requires design and secure operations

Open source based firewalls

- Linux firewalls IP tables, use command line tool ufw Uncomplicated Firewall!
- Firewall GUIs on top of Linux – lots! Some are also available as commercial ones
- OpenBSD PF http://www.openbsd.org
- FreeBSD IPFW og IPFW2 http://www.freebsd.org
- Mac OS X uses OpenBSD PF
- FreeBSD has an older version of the OpenBSD PF, should really be renamed now

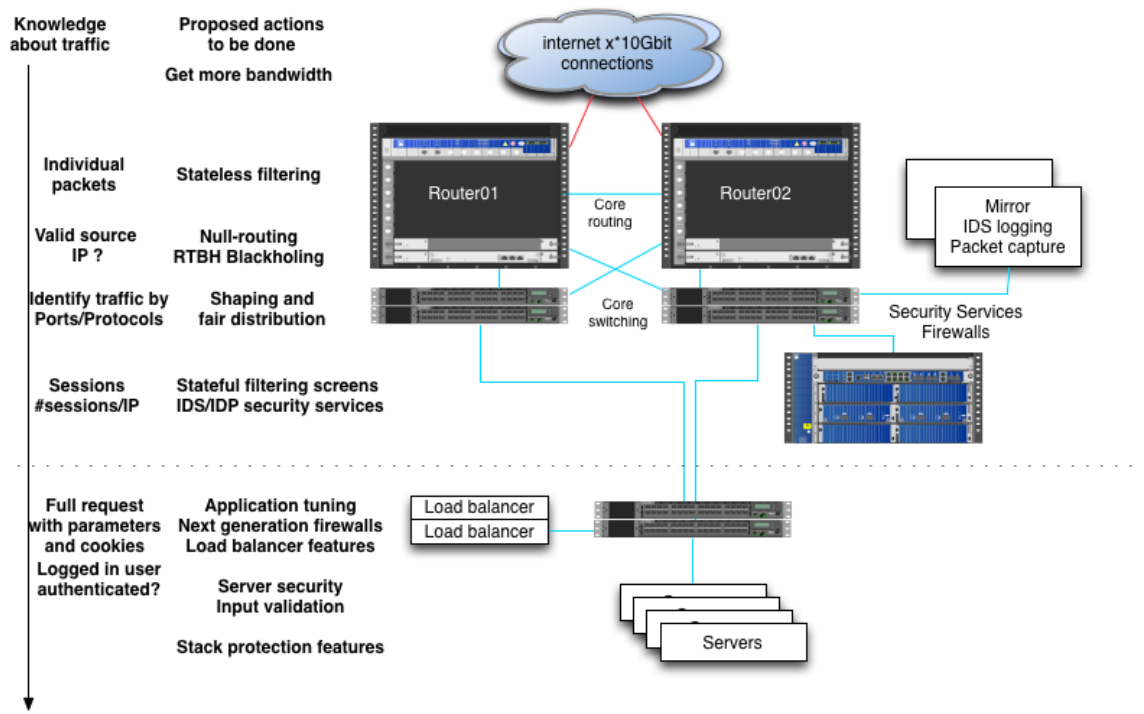
Uncomplicated Firewall (UFW)

```
root@debian01:~# apt install ufw
...
root@debian01:~# ufw allow 22/tcp
Rules updated
Rules updated (v6)
root@debian01:~# ufw enable
Command may disrupt existing ssh connections. Proceed with operation (y|n)? y
Firewall is active and enabled on system startup
root@debian01:~# ufw status numbered
Status: active

     To                         Action      From
     --                         ------      ----
[ 1] 22/tcp                     ALLOW IN    Anywhere
[ 2] 22/tcp (v6)                ALLOW IN    Anywhere (v6)
```

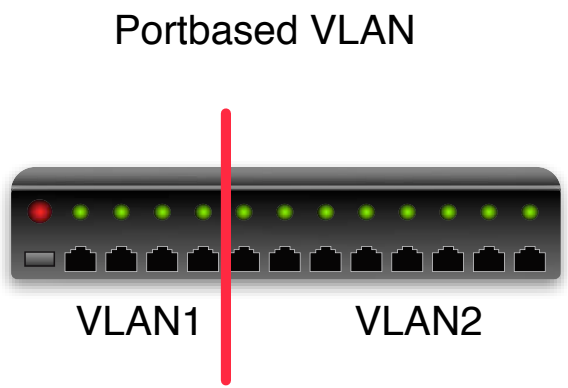
- Extremely easy to use – I recommend and use the (Uncomplicated Firewall) UFW

Firewalls are NOT Alone



Use Defense in Depth – all layers have features

Together with Firewalls - Virtual LAN (VLAN)



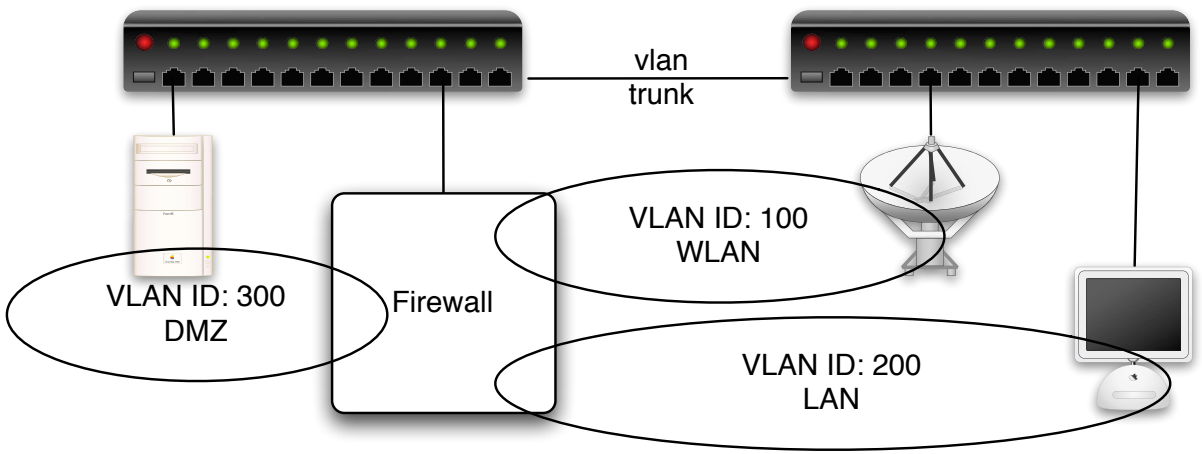
Managed switches often allow splitting into zones called virtual LANs

Most simple version is port based

Like putting ports 1-4 into one LAN and remaining in another LAN

Packets must traverse a router or firewall to cross between VLANs

Virtual LAN (VLAN) IEEE 802.1q

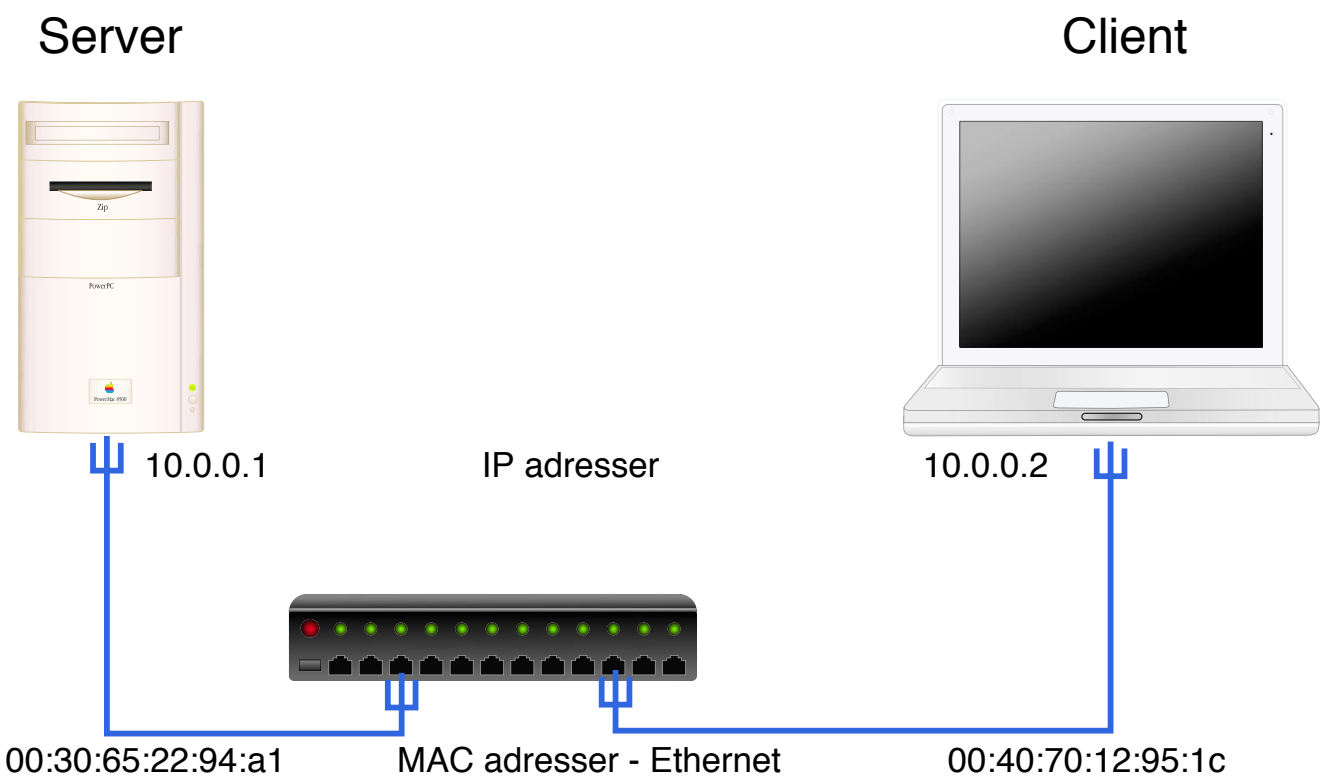


Using IEEE 802.1q VLAN tagging on Ethernet frames

Virtual LAN, to pass from one to another, must use a router/firewall

Allows separation/segmentation and protects traffic from many security issues

ARP in IPv4


Server
Client
10.0.0.1
IP adresser
10.0.0.2
00:30:65:22:94:a1
MAC adresser - Ethernet
00:40:70:12:95:1c

ARP request and reply

ping 10.0.0.2 from server

ARP Address Resolution Protocol request/reply:

- ARP request broadcasted on layer 2 - Who has 10.0.0.2 Tell 10.0.0.1
- ARP reply (from 10.0.0.2) 10.0.0.2 is at 00:40:70:12:95:1c

IP ICMP request/reply:

- Echo (ping) request from 10.0.0.1 to 10.0.0.2
- Echo (ping) reply from 10.0.0.2 to 10.0.0.1
- ...

ARP is performed on Ethernet before IP can be transmitted

IPv6 neighbor discovery protocol (NDP)

OSI	IPv4	IPv6
Network	IP / ICMP	IPv6 / ICMPv6
Link	ARP	
Physical	Physical	Physical

NDP replaces ARP, compare `arp -an` and `ndp -an`

RFC4861 Neighbor Discovery for IP version 6 (IPv6)

Hello neighbors

```
$ ping6 -w -I en1 ff02::1
PING6(72=40+8+24 bytes) fe80::223:6cff:fe9a:f52c%en1 --> ff02::1
30 bytes from fe80::223:6cff:fe9a:f52c%en1: bigfoot
36 bytes from fe80::216:cbff:feac:1d9f%en1: mike.kramse.dk.
38 bytes from fe80::200:aaff:feab:9f06%en1: xrx0000aaab9f06
34 bytes from fe80::20d:93ff:fe4d:55fe%en1: harry.local
36 bytes from fe80::200:24ff:fec8:b24c%en1: kris.kramse.dk.
31 bytes from fe80::21b:63ff:fef5:38df%en1: airport5
32 bytes from fe80::216:cbff:fec4:403a%en1: main-base
44 bytes from fe80::217:f2ff:fee4:2156%en1: Base Station Koekken
35 bytes from fe80::21e:c2ff:feac:cd17%en1: arnold.local
```

Exercise

Now lets do the exercise

⚠ Enable firewall - 15min

which is number **5** in the exercise PDF.