10th Slide Set
Computer Networks

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Session Layer

- Provides the functionality for establishment, monitoring and termination of sessions
  - A session is the basis for a virtual connection between two applications on physically independent computers
  - A session consists of requests and replies between applications
- Furthermore, this layer provides the dialogue control functionality (which participant speaks right now)
- Functions for synchronization
  - Checkpoints can be inserted into large data transmissions for session restoration
  - If the connection fails, the transmission can continue at the latest checkpoint and does not need to start again from the beginning

Session Layer Protocols

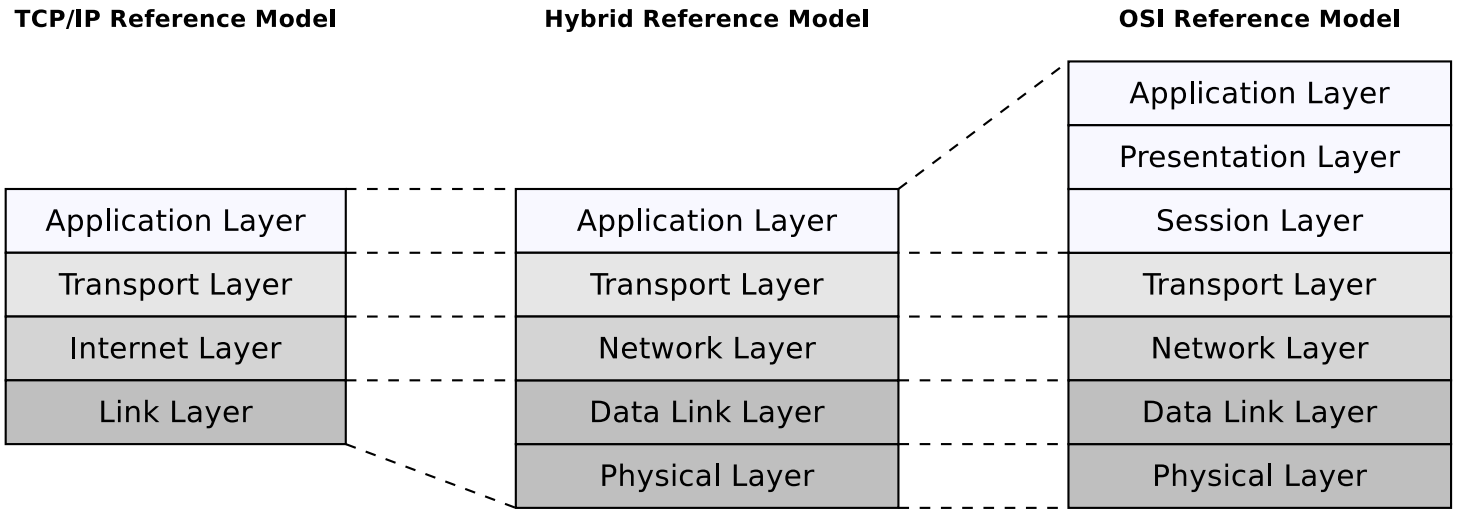
- Protocols, which meet the required features of the Session Layer, are e.g. Telnet for the remote controlling of computers and FTP for transferring files
  - However, these protocols can also be assigned to the Application Layer
- The Application Layer contains the protocols, which are used by the applications
- Telnet and FTP are used directly by the corresponding application programs, and not by abstract protocols at upper protocols layers
  - Therefore, it is useful to assign the Session Layer protocols to the Application Layer

Presentation Layer

- Contains rules for the formatting (presentation) of message
  - The sender can inform the receiver that a message is encoded in a specific format (e.g. ASCII)
    - Objective: Enable the receiver to do the necessary conversion
  - In this layer, data records can assigned to fields (e.g. name, student ID number...)
  - The type and length of data types can be specified here
  - Compression and encryption are assigned to the Presentation Layer
- Exactly like the Session Layer, the Presentation Layer is hardly used in practice
  - Reason: All features of this layer are provided by Application Layer protocols today

Application Layer

- Contains the protocols, which interact with applications (e.g. browser or email client)
- Contains the messages of the users and their applications (e.g. HTML pages or emails) in accordance with the Application Layer protocol used



Exercise sheet 5 repeats the contents of this slide set which are relevant for these learning objectives

- Devices: none
- Protocols: DNS, DHCP, NTP, Telnet, SSH, HTTP, SMTP, FTP...

Learning Objectives of this Slide Set

- Session Layer
- Presentation Layer
- Application Layer
  - Application Layer protocols
    - Domain name resolution (DNS)
    - Automatic assignment of addresses (DHCP)
    - Time synchronization (NTP)
    - Remote control of computers (Telnet, SSH)
    - Transferring data (HTTP)
    - Exchange emails (SMTP)
    - Retrieve emails (POP3)
    - ~~Upload and download files (FTP)~~

Domain Name System (DNS)

- Protocol for the **resolution** of domain names to IP addresses

RFC 1034 and 1035

- Similar to a telephone assistance
  - Person/family/company $\Longrightarrow$ telephone number
  - Hostname/website $\Longrightarrow$ IP address

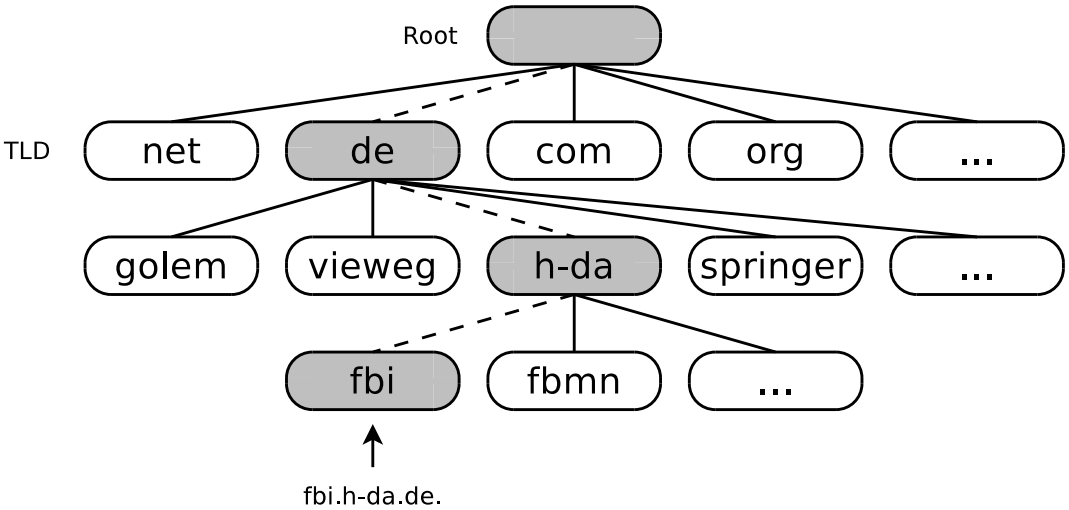
Developed in 1983 by Paul Mockapetris

- DNS replaced the local domain name tables in the config file `/etc/hosts`, which until then had been used for managing the domain names/IP addresses mappings
  - These were no longer able to handle the growing number of new entries
- Bases on a hierarchical namespace
  - The assignment records are split into separate parts and distributed to **name servers** across the internet

Domain Namespace (1/2)

- The domain namespace consists of a **tree of domain names**
  - Leaves and nodes are called **labels**
  - Each subtree is a **domain**
- A complete domain name consists of the concatenation of all labels of a path
- Labels are alphanumeric character strings
  - The dash (-) is the only special character allowed
  - The length of a label must be at least 1 and can be up to 63 characters
  - Labels cannot start or end with a dash
  - Each labels ends with a period
- Domain names end with a period
  - The period is usually omitted, but from a formal perspective, a complete domain name – **Fully Qualified Domain-Name** (FQDN) ends with a period
- An example for a complete domain name is `www.h-da.de.`

Domain Namespace (2/2)



- Domain names are resolved from right to left
  - The further right a label is, the upper located is it in the tree

- The first layer below root is called **top level domain** (TLD)
- The DNS objects of a domain (e.g. the hostname) are stored as a set of **resource records** (RR) in a zone file, which is stored at one or more name servers
- The zone file is often simply called **zone**

Root-Nameserver

http://www.root-servers.org (May 2020)

- The 13 root name servers (`A` to `M`) publish the DNS **root zone**
  - Their domain names have the form `letter.root-servers.net`
  - The root zone contains approx. 3000 entries and is the root of the DNS
    - It contains the hostnames and IP addresses of the name servers, which are responsible for the TLDs
- Root servers do not consist of a single, but multiple physical servers, which are connected to a logical server
  - These computers are located at different locations around the world and can be reached via **anycast** using the same IP address

Name	IPv4 address	IPv6 address	Location	Sites	Operator
A	198.41.0.4	2001:503:ba3e::2:30	distributed (Anycast)	53	Verisign, Inc.
B	199.9.14.201	2001:500:200::b	distributed (Anycast)	6	Information Sciences Institute
C	192.33.4.12	2001:500:2::c	distributed (Anycast)	10	Cogent Communications
D	199.7.91.13	2001:500:2d::d	distributed (Anycast)	156	University of Maryland
E	192.203.230.10	2001:500:a8::e	distributed (Anycast)	308	NASA Ames Research Center
F	192.5.5.241	2001:500:2f::f	distributed (Anycast)	252	Internet Systems Consortium, Inc.
G	192.112.36.4	2001:500:12::d0d	distributed (Anycast)	6	Defense Information Systems Agency
H	198.97.190.53	2001:500:1::53	distributed (Anycast)	8	U.S. Army Research Lab
I	192.36.148.17	2001:7fe::53	distributed (Anycast)	72	Netnod
J	192.58.128.30	2001:503:c27::2:30	distributed (Anycast)	185	Verisign, Inc.
K	193.0.14.129	2001:7fd::1	distributed (Anycast)	77	RIPE NCC
L	199.7.83.42	2001:500:9f::42	distributed (Anycast)	165	ICANN
M	202.12.27.33	2001:dc3::35	distributed (Anycast)	9	WIDE Project

Structure of the DNS Database and the Resource Records

You already know...

- DNS implements a distributed database with a tree structure
- The data of the DNS of the internet is stored on globally distributed servers, with are linked to each other via references (*delegations*)
- In each name server, ≥ 1 zone files exist

- The zone files contain lists of resource records (RR)
- Every RR consists of 5 elements
  `<Name, Value, Type, Class, TTL>`
- The table contains some types of RRs

Type	Description
`NS`	Specifies the name server which is responsible for the zone or links zones to a tree of zones (delegation)
`A`	Specifies the IPv4 address of a host
`AAAA`	Specifies the IPv6 address of a host
`SOA`	Contains information for the management of the zone, such as the name and email address of the administrator
`CNAME`	Specifies an alias domain name for a specific host
`MX`	Assigns a SMTP mail server to a name. All other services use `CNAME`, `A` and `AAAA` resource records for the name resolution
`PTR`	Assigns an IP address to one or more hostname(s). Counterpart to the usual assignment of one or more IPs to a host name via an `A` or `AAAA` resource record

Example of a Domain Name Resolution (1/5)

- In this example, the domain name `www.fh-frankfurt.de.` is resolved with the command line tool `dig`

```
dig +trace +additional -t A www.fh-frankfurt.de.
```

- `-t A` $\Longrightarrow$ request the `A` resource record (the IPv4 address)
- `+trace` $\Longrightarrow$ print the individual replies on the path through the name server hierarchy
- `+additional` $\Longrightarrow$ name servers sometimes store for delegations not only the `NS` resource records, but also their IP addresses in form of `A` or `AAAA` RRs. Print them, if they are delivered

- For resolving the IP, 4 name servers have to be consulted one by one

The output of `dig` on the following slides contains several DNSSEC Resource Records (RR). DNSSEC provides authenticity and integrity of DNS data

- `RRSIG` = Signature Resource Record = Digital signature of a DNS Resource Record Set
- `NSEC3` = Hashed next secure entry within the zone (*chain-of-trust*)
- `DS` = Delegation Signer = Used to concatenate DNSSEC-signed zones. This way, several DNS zones are combined into a chain-of-trust and can be validated with a single public key

Example of a Domain Name Resolution (2/5)

```
$ dig +trace +additional -t A www.fh-frankfurt.de.

; <<>> DiG 9.10.3-P4-Debian <<>> +trace +additional -t A www.fh-frankfurt.de.
;; global options: +cmd
.                       515463  IN      NS      a.root-servers.net.
.                       515463  IN      NS      b.root-servers.net.
.                       515463  IN      NS      c.root-servers.net.
.                       515463  IN      NS      d.root-servers.net.
.                       515463  IN      NS      e.root-servers.net.
.                       515463  IN      NS      f.root-servers.net.
.                       515463  IN      NS      g.root-servers.net.
.                       515463  IN      NS      h.root-servers.net.
.                       515463  IN      NS      i.root-servers.net.
.                       515463  IN      NS      j.root-servers.net.
.                       515463  IN      NS      k.root-servers.net.
.                       515463  IN      NS      l.root-servers.net.
.                       515463  IN      NS      m.root-servers.net.
.                       515463  IN      RRSIG   NS 8 0 518400 20200602050000 2020052...
;; Received 525 bytes from 10.0.0.2#53(10.0.0.2) in 12 ms
```

- The final line contains the IP address 10.0.0.2 of the name server of the requesting host
  - This name server knows the IP addresses of the root name servers
  - IP addresses of root name servers change seldom and must be well-known by all name servers, if they answer requests concerning the internet

Example of a Domain Name Resolution (3/5)

```
de.                     172800  IN      NS      s.de.net.
de.                     172800  IN      NS      n.de.net.
de.                     172800  IN      NS      a.nic.de.
de.                     172800  IN      NS      f.nic.de.
de.                     172800  IN      NS      l.de.net.
de.                     172800  IN      NS      z.nic.de.
de.                     86400   IN      DS      45580 8 2 918C32E2F12211766...
s.de.net.               172800  IN      A       195.243.137.26
s.de.net.               172800  IN      AAAA    2003:8:14::53
n.de.net.               172800  IN      A       194.146.107.6
n.de.net.               172800  IN      AAAA    2001:67c:1011:1::53
a.nic.de.               172800  IN      A       194.0.0.53
a.nic.de.               172800  IN      AAAA    2001:678:2::53
f.nic.de.               172800  IN      A       81.91.164.5
f.nic.de.               172800  IN      AAAA    2a02:568:0:2::53
l.de.net.               172800  IN      A       77.67.63.105
l.de.net.               172800  IN      AAAA    2001:668:1f:11::105
z.nic.de.               172800  IN      A       194.246.96.1
z.nic.de.               172800  IN      AAAA    2a02:568:fe02::de
;; Received 753 bytes from 198.41.0.4#53(a.root-servers.net) in 24 ms
```

- From the 13 root name servers, `a.root-servers.net` was randomly chosen, to send it the request for `www.fh-frankfurt.de.`
- The reply contains 6 name servers (delegations) to choose from, which are responsible for the zone `de.`
  - For all servers, using IPv6 (`AAAA`) for the request is possible

Beispiel einer Namensauflösung (4/5)

```
fh-frankfurt.de.          86400   IN      NS      deneb.dfn.de.
fh-frankfurt.de.          86400   IN      NS      medusa.fh-frankfurt.de.
tjlb7qboj...s1lg16.de. 7200 IN NSEC3 1 1 15 CA12B74...R67IU NS SOA RRSIG DNSKEY NSEC3PARAM
ck6ochdub...5a0eut.de. 7200 IN NSEC3 1 1 15 CA12B74...KPHCB A RRSIG
tjlb7qboj...s1lg16.de. 7200 IN RRSIG NSEC3 8 2 7200 20200528085231 2020051...
ck6ochdub...5a0eut.de. 7200 IN RRSIG NSEC3 8 2 7200 20200528095239 2020051...
medusa.fh-frankfurt.de. 86400   IN      A       192.109.234.209
deneb.dfn.de.           86400   IN      A       192.76.176.9
;; Received 637 bytes from 77.67.63.105#53(l.de.net) in 23 ms
```

- From the 6 name servers in the reply, `l.de.net` has been randomly chosen, to send it the request for `www.fh-frankfurt.de.`
- The reply contains 2 name servers (delegations) to choose from, which are responsible for the zone `fh-frankfurt.`

Example of a Domain Name Resolution (5/5)

```
www.fh-frankfurt.de.     86400   IN      CNAME   squid01.dv.fh-frankfurt.de.
squid01.dv.fh-frankfurt.de. 86400 IN     A       192.109.234.216
fh-frankfurt.de.         86400   IN      NS      deneb.dfn.de.
fh-frankfurt.de.         86400   IN      NS      medusa.fh-frankfurt.de.
deneb.dfn.de.            86400   IN      A       192.76.176.9
medusa.fh-frankfurt.de. 86400    IN      A       192.109.234.209
;; Received 166 bytes from 192.76.176.9#53(deneb.dfn.de) in 23 ms
```

- From the 2 name servers in the reply, `deneb.dfn.de` has been randomly chosen, to send it the request for `www.fh-frankfurt.de.`
- `www.fh-frankfurt.de.` is just an alias (`CNAME`) for `squid01.dv.fh-frankfurt.de.`
- Result: The IP of `www.fh-frankfurt.de.` or `squid01.dv.fh-frankfurt.de.` is 192.109.234.216

The DNS protocol

- DNS requests are usually sent via UDP port 53 to the server name
- The maximum length of a DNS reply via UDP is 512 bytes
- Longer DNS replies sends a Nameserver via TCP

Dynamic Host Configuration Protocol (DHCP)

- Is used to assign the network configuration (IP address, network mask, default gateway, name server, etc.) to network devices from a **DHCP server** by using a **DHCP client**
  - Especially for mobile devices, it is not useful to assign static IPs
    - Without DHCP, the network settings of all clients need to be customized after modifying the network topology
    - With DHCP, just the DHCP server's configuration need to be adjusted
- Uses UDP via ports 67 (server or relay agent) and 68 (client)

RFC 2131

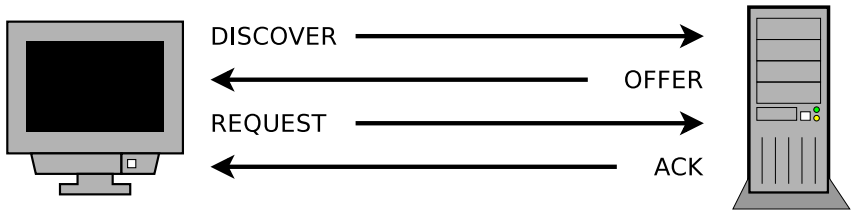
- A DHCP server has a **pool of IPs** and distributes them to clients
- A DHCP client can only use a DHCP server, when both are connected to the **same logical network**
  - Reason: DHCP uses **broadcasts** and Routers do not forward broadcasts

If the DHCP server is connected with a different logical network, a **DHCP relay** need to forward the requests to the DHCP server

Functioning of DHCP (1/2)

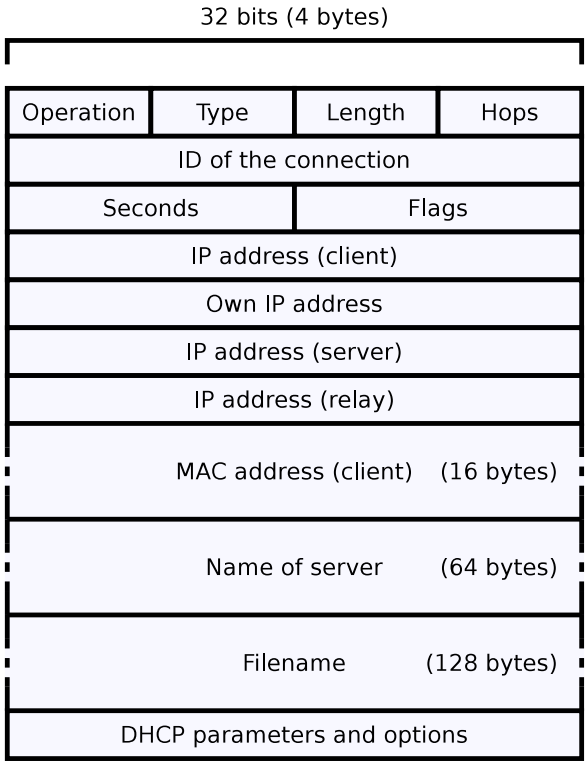
1. A client without an IP address sends via **broadcast** a request (**DHCP Discover**) to the DHCP servers, that can be reached by it
   - The sender IP address of the broadcast is 0.0.0.0 and the destination address is 255.255.255.255
2. Each DHCP server, which receives the **broadcast** and has free IPs in its pool, responds to the request with an address offering (**DHCP Offer**)
   - The address offer is sent as **broadcast** (destination address: 255.255.255.255) or **unicast** (to the offered IP address)
   - Whether broadcast or unicast is used depends on if the client has set the broadcast bit in the DHCP Discover message
3. The DHCP client accepts an address offering by sending a request (**DHCP Request**) via **broadcast**
   - The message contains the ID of the desired DHCP server
   - Any other (possibly existing) DHCP servers understand the message as a rejection of their address offers
4. The server acknowledges the address request with **DHCP Ack** via **broadcast** or **unicast** and marks the IP in its address pool as assigned
   - Whether broadcast or unicast is used depends on if the client has set the broadcast bit in the DHCP Discover message
   - It can also refuse the request with **DHCP Nak**

Functioning of DHCP (2/2)



- If a DHCP server has assigned an IP and acknowledged this via **DHCP Ack**, it creates a *lease* record for the address in its database
  - If all addresses are assigned (leased), no further clients can be supplied with IP addresses
- Each address has an expiration date (*lease time)*, which is transmitted to the client via the acknowledgement (**DHCP Ack**)
  - Active clients periodically renew the lease after the half lease time has expired via **DHCP Request**, which is sent via **unicast** directly to the server and not via broadcast
  - The server again responds with an acknowledgement (**DHCP Ack**), which contains the same data as before and a new expiration date
  - If the expiration date has expired, the server can assign the address new, when requests arrive

Structure of DHCP Messages



- **Operation** specifies the sort of the DHCP message
  - 1 = Request of a Client
  - 2 = Reply of a Server
- **Type** specifies the networking technology
  - 1 = Ethernet, 6 = WLAN
- **Length** contains the length of the physical network address in bytes
- **Hops** is optional and contains the number of DHCP Relays on the path
- **Flags** indicates if the client still has a valid IP address
- **Filename** is optional and contains the name of a file, which the client is supposed to fetch via Trivial File Transfer Protocol (TFTP)
  - This allows a terminal device to boot via the network

Network Time Protocol (NTP)

- Standard for clock synchronization between computer systems

RFC 5905 describes the protocol and algorithms in detail

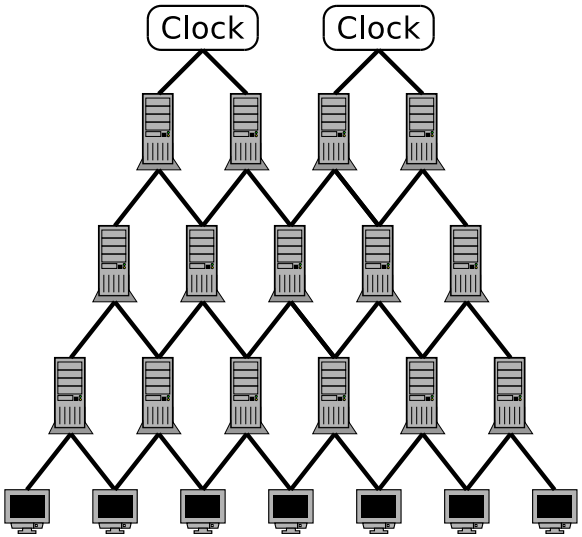
- NTP is the name of the protocol and of the reference implementation
  - Uses UDP via port 123

Developed in 1985 by David L. Mills of the University of Delaware

- The local clock is synchronized by the local background process (daemon) of the NTP software with an external time signal (e.g. atomic clock, local radio receiver or remote NTP servers via NTP)
- The timestamps in NTP have a length of 64 bits
  - 32 bits contain the *UNIX time* (seconds since 1.1.1970 00:00:00)
  - 32 bits contain the fractional second
  - Therefore, NTP can be used for a time scale of 2^{32} seconds (approx. 136 years) and it has a resolution of 2^{-32} seconds (0.23 nanoseconds)

Hierarchical Structure of a Network of NTP Servers

- NTP uses a hierarchical system of so-called *strata*
  - Stratum 0 is an atomic clock or a radio clock based on the time signal transmitter DCF77 or the Global Navigation Satellite System GPS
  - Stratum 1 are the NTP servers (*time servers*), which are coupled directly to stratum 0
  - Several lower levels exist, which contain among others the terminal devices
  - The stratum level specifies the distance from stratum 0



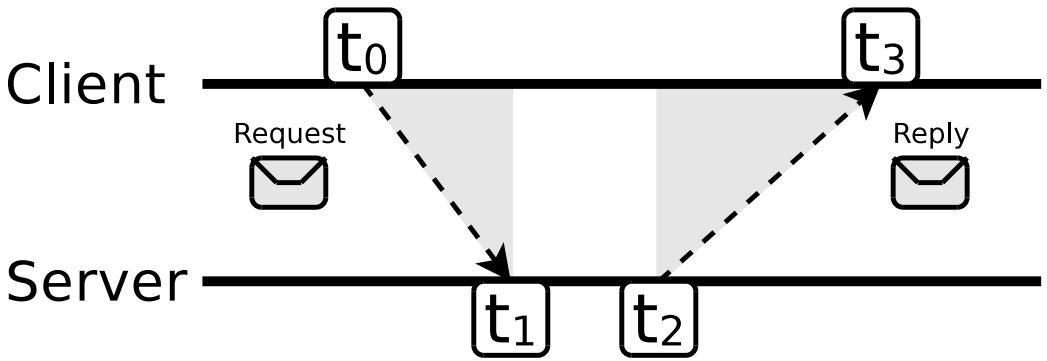
- The NTP software on stratum 1, 2 and so on, acts as client for the overlying stratum and as server for the underlying stratum, if it exists
- NTP uses the UTC time scale
- $>$ 100,000 NTP nodes exist worldwide

A Stratum 0 Clock Source for NTP

U.S. Naval Observatory – Schriever Air Force Base in Colorado. License: CC0
Image source: `http://www.af.mil/shared/media/photodb/photos/060104-F-3966R-005.jpg`

Clock Synchronization Algorithm of NTP

- To synchronize its local clock with a remote NTP server, a NTP client needs to compute the round-trip delay time and the offset
  - Timestamp t_0: Client sends the request
  - Timestamp t_1: Server receives the request
  - Timestamp t_2: Server sends the reply
  - Timestamp t_3: Client receives the reply
  - $t_3 - t_0 \Longrightarrow$ time elapsed on client side between the request is send and the reply is received
  - $t_2 - t_1 \Longrightarrow$ time elapsed on server side between the request is received and the reply is send



- Round trip delay time = $(t_3 - t_0) - (t_2 - t_1)$
- Offset = $\frac{(t_1 - t_0) + (t_2 - t_3)}{2}$

Output of the NTP Daemon

- Typically, a NTP client polls ≥ 3 NTP servers in different networks
  - Outliers are discarded
  - An estimate time offset is calculated from the best candidates

```
$ ntpq -p
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
+foxtrot.zq1.de  235.106.237.243  3 u  247 1024  277    49.765   -2.701  46.993
*ns2.customer-re 40.33.41.76      2 u  331 1024  377    50.853    0.390 234.340
+nono.com        78.46.60.42      3 u  746 1024  377    50.469    0.307  28.140
+thw23.de        52.239.121.49    3 u  969 1024  377    51.589    0.308  58.305
```

- 1st column: DNS name of NTP server used
- 2nd column: IP of NTP server used
- 3rd column: Stratum of the NTP server
- 4th column: Type of NTP server (`u` = Unicast)
- 5th column: `when` was the last request (in seconds)
- 6th column: Interval of requests
- 7th column: How often the NTP server was successfully reached (377 = the last 8 times)
- 8th column: `delay` = Round Trip Time
- 9th column: `offset` of the local clock against the NTP server
- 10th column: `jitter` = deviation of the transmission timing

Telnet (Telecommunication Network)

- Protocol (RFC 854) for the remote control of computers
  - Provides character-oriented communication via **TCP** (default port: 23)
  - Suitable only for applications without a graphical user interface
- Software, which implements the protocol, is also simply called Telnet
  - Consists of the Telnet client and Telnet server
- Drawback: **No encryption!**
  - Also, the passwords are transmitted as plain text
    $\Longrightarrow$ insufficient security for remote work
  - Successor: Secure Shell (SSH)
- Is often used for investigating issues of different services, such as web servers, FTP servers or SMTP servers, and for the administration of databases, and it is used in LANs
- Telnet clients are able to **connect to any port number**
  - This enables the administrator to send via a Telnet client requests (commands) to web servers, FTP servers or SMTP servers without an intermediate step and observe their reaction

Telnet and the Virtual Network Terminal

- Telnet is based on the NVT standard
  - NVT (Network Virtual Terminal) = virtual network terminal
    - Telnet clients convert the keystrokes and control characters into the NVT format and send this data to the Telnet server, which in turn decodes and forwards them
  - NVT uses data units, each of a size of 8 bits (1 byte)
    - NVT uses the 7-bit US-ASCII character encoding
    - The most significant bit of each character is filled with a zero bit

Name	Code	Description
NULL	NUL	No operation
Line Feed	LF	Moves the cursor to the next line and keeps the column
Carriage Return	CR	Moves the cursor to the 1st column of the current line
BELL	BEL	Produces an audible or visible signal
Back Space	BS	Moves the cursor one position back
Horizontal Tab	HT	Moves the cursor to next horizontal tab stop
Vertical Tab	VT	Moves the cursor to the next vertical tab stop
Form Feed	FF	Moves the cursor to the 1st column of the 1st line and clears the terminal

The table contains the control characters of NVT

The first 3 control characters are implemented by each Telnet client and server. The remaining 5 control characters are optional

Secure Shell (SSH)

- Provides an encrypted and therefore secure communication between 2 hosts over an insecure network
  - Secure alternative to Telnet
- Uses TCP (default port: 22)

- SSH-1 was developed in 1995 by Tatu Ylönen and released as freeware
- Open Source alternative: OpenSSH (`http://openssh.com`)
- SSH-2 was released in 1996 and provides, among others, improved integrity checking

- Any TCP/IP connection can be tunneled over SSH (port forwarding)
  - Common application: Tunneling an X11 applications via SSH
- SSH-2 uses the AES encryption algorithm with a key length of 128 bits
  - 3DES, Blowfish, Twofish, CAST, IDEA, Arcfour, SEED and AES with other key lengths are supported too

Hypertext Transfer Protocol (HTTP)

- The Hypertext Transfer Protocol (HTTP) is a stateless protocol for data transmission
  - Stateless means that every HTTP message contains all the information necessary to understand the message
  - The server does not maintain any information regarding the state or session for the client, and each request is a transaction, independent of other requests

HTTP

From 1989 onwards, developed by Roy Fielding, Tim Berners-Lee and other at CERN

- Together with the concepts of URL and HTML it is the basis of the World Wide Web (WWW)
- Main purpose: Loading web pages from the World Wide Web (WWW) in a browser
- For communication, HTTP needs a reliable transport protocol
  - In almost all cases, TCP is used
- Each HTTP message consists of:
  - Message header (*HTTP header*): Includes among others Information about the encoding, desired language, browser and content type
  - Message body (*body*): Contains the payload, e.g. the HTML source code of a web page

HTTP Requests (1/2)

- If an URL is accessed via HTTP (e.g. `http://www.informatik.hs-mannheim.de/~baun/index.html`, the request for the resource `/~baun/index.html` is transmitted to the computer with hostname `www.informatik.hs-mannheim.de`
- First, via DNS, the hostname is resolved to an IP address
- Next, this HTTP `GET` request is transmitted via TCP to port 80, where the web server usually operates

```
GET /~baun/index.html HTTP/1.1
Host: www.informatik.hs-mannheim.de
User-Agent: Mozilla/5.0 (X11; U; Linux i686; de; rv:1.9.2.18) Gecko/20110628 Ubuntu/10.10 (
     maverick) Firefox/3.6.18
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: de-de,de;q=0.8,en-us;q=0.5,en;q=0.3
Accept-Encoding: gzip,deflate
Accept-Charset: ISO-8859-1,utf-8;q=0.7,*;q=0.7
Keep-Alive: 115
Connection: keep-alive
...
```

HTTP Requests (2/2)

- A this large message header is not required
- The HTTP `GET` request below is sufficient

```
GET /~baun/index.html HTTP/1.1
Host: www.informatik.hs-mannheim.de
```

- The header of a HTTP message is separated from the message body with a line feed (`LF`) and a carriage return (`CR`)
  - In this example, the HTTP request has no message body

HTTP Responses (1/2)

- The HTTP response of the web server consists of a message header and the message body with the actual message
  - In this case, the message body contains the content of the requested file `index.html`

```
HTTP/1.1 200 OK
Date: Sun, 04 Sep 2011 15:19:13 GMT
Server: Apache/2.2.17 (Fedora)
Last-Modified: Mon, 22 Aug 2011 12:37:04 GMT
ETag: "101ec1-2157-4ab17561a3c00"
Accept-Ranges: bytes
Content-Length: 8535
Keep-Alive: timeout=13, max=499
Connection: Keep-Alive
Content-Type: text/html

<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN"
        "http://www.w3.org/TR/html4/loose.dtd">
<html>
...
</html>
```

HTTP Responses (2/2)

- Each HTTP response contains a **status code**, which consists of 3 digits, and a text string, which describes the reason for the response

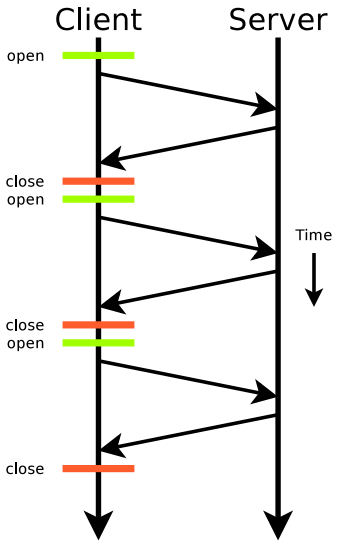
Status code	Meaning	Description
1xx	**Informational**	Request received, continuing process
2xx	**Success operation**	Action received, understood, accepted and processed successfully
3xx	**Redirection**	Additional action must be taken by the client to complete the request
4xx	**Client error**	Request of the client caused an error situation
5xx	**Server error**	Server failed to fulfill a valid request $\Longrightarrow$ error was caused by server

- The table contains some common status codes of HTTP

Status code	Meaning	Description
200	`OK`	Request processed successfully. Result is transmitted in the response
202	`Accepted`	Request accepted, but will be executed at a later point in time
204	`No Content`	Request executed successfully. Response intentionally contains no data
301	`Moved Permanently`	The old address is no longer valid
307	`Temporary Redirect`	Resource moved. The old address remains valid
400	`Bad Request`	Request cannot be fulfilled due to bad syntax
401	`Unauthorized`	Request can not be executed without a valid authentication
403	`Forbidden`	Request is executed because of clients lack of privileges
404	`Not Found`	Server could not find the requested resource
500	`Internal Server Error`	Unexpected server error

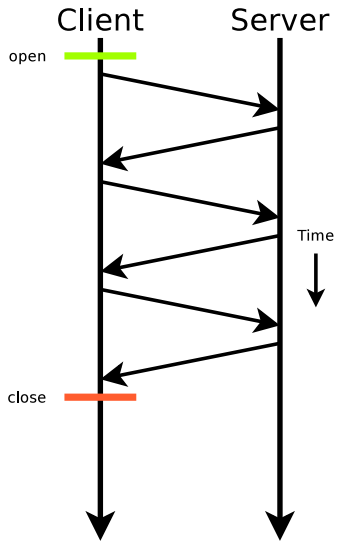
HTTP Protocol Versions (HTTP/1.0 and HTTP/1.1)

- 3 protocol versions exist: `HTTP/1.0`, `HTTP/1.1` and `HTTP/2`



- HTTP/1.0 (RFC 1945): Prior to any request, a new TCP connection is established and closed by default by the server after the transmission of the reply
  - If a HTML document contains e.g. 10 images, 11 TCP connections are required for the transmission to the client

- HTTP/1.1 (RFC 2616): By default, no connection termination is done
  - So the connection can be used again and again
  - Therefore, only a single TCP connection is required for the transfer of a HTML document with 10 images
    - Result: The document download finishes in a shorter time
  - Interrupted transmissions can be resumed with `HTTP/1.1`



HTTP Protocol Versions (HTTP/2)

- `HTTP/2` (RFC 7540) became a standard in May 2015
- Accelerates the data transfer by compressing the header with the HPACK algorithm (RFC 7541)
- Enables the aggregation (*Multiplex*) of requests and a server can send (*Server Push*) data automatically, which it expects the browser to request immediately
  - Examples of such data are CSS files (Cascading Style Sheets), which specify the layout of web pages, or script files
- `HTTP/2` is not a text-based but a binary protocol
  - Therefore it cannot be used to communicate using simple tools like `telnet` and `nc` e.g. to inspect a server
  - Tools like `curl` and `openssl -connect` can communicate via HTTP/2

Some sources about `curl` and `openssl`

`https://stackoverflow.com/questions/51278076/curl-one-liner-to-test-http-2-support`
`https://blog.cloudflare.com/tools-for-debugging-testing-and-using-http-2/`
Stephen Ludin, Javier Garza. **Learning HTTP/2: A Practical Guide for Beginners**. O'Reilly Media, Inc (2017)

HTTP Methods

- The HTTP protocol provides some methods for requests

HTTP	Description
`PUT`	Upload a new resource to the web server
`GET`	Request a resource from the web server
`POST`	Upload data to the web server in order to generate resources
`DELETE`	Erase a resource on the web server
`HEAD`	Request the header of a resource from the web server, but not the body
`TRACE`	Returns the request back, as the web server has received it. Helpful for troubleshooting purposes
`OPTIONS`	Request the list of supported HTTP methods from the web server
`CONNECT`	Establish a SSL tunnel with a proxy

HTTP is a stateless protocol. But via cookies in the header information, applications can be implemented which require state or session information because they assign user information or shopping carts to clients.

Web Servers can be tested via Telnet (1/2)

```
$ telnet www.informatik.hs-mannheim.de 80
Trying 141.19.145.2...
Connected to anja.ki.fh-mannheim.de.
Escape character is '^]'.
GET /~baun/index.html HTTP/1.0

HTTP/1.1 200 OK
Date: Sun, 04 Sep 2011 21:43:53 GMT
Server: Apache/2.2.17 (Fedora)
Last-Modified: Mon, 22 Aug 2011 12:37:04 GMT
ETag: "101ec1-2157-4ab17561a3c00"
Accept-Ranges: bytes
Content-Length: 8535
Connection: close
Content-Type: text/html
X-Pad: avoid browser bug

<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN"
        "http://www.w3.org/TR/html4/loose.dtd">
<html>
<head>
<meta http-equiv="Content-Type" content="text/html; charset=iso-8859-1">
...
</body>
</html>
Connection closed by foreign host.
```

When encryption is used: `openssl s_client -connect <server>:<port>`

Web Servers can be tested via Telnet (2/2)

```
$ telnet www.informatik.hs-mannheim.de 80
Trying 141.19.145.2...
Connected to anja.ki.fh-mannheim.de.
Escape character is '^]'.
GET /~baun/test.html HTTP/1.0

HTTP/1.1 404 Not Found
Date: Sun, 04 Sep 2011 21:47:26 GMT
Server: Apache/2.2.17 (Fedora)
Content-Length: 301
Connection: close
Content-Type: text/html; charset=iso-8859-1

<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML 2.0//EN">
<html><head>
<title>404 Not Found</title>
</head><body>
<h1>Not Found</h1>
<p>The requested URL /~baun/test.html was not found on this server.</p>
<hr>
<address>Apache/2.2.17 (Fedora) Server at anja.ki.hs-mannheim.de Port 80</address>
</body></html>
Connection closed by foreign host.
```

Simple Mail Transfer Protocol (SMTP)

- Protocol (RFC 5321), which allows the exchange (delivery) of emails
- Uses TCP (default port: 25)
- Fetching emails is done with the protocols POP3 or IMAP
- For sending emails, the user's mail program connects to a SMTP server, which forwards the emails, if necessary via additional SMTP servers, to the target
- Because SMTP is a text-based protocol, it is possible to connect via telnet to a SMTP server and send emails *manually*
  - The sender and destination addresses are freely selectable with SMTP
    - The addresses in the commands `MAIL FROM` and `RCPT TO` can be different from the addresses in the fields `From` and `To` in the header of the email
  - Authentication is not required and does not take place by default
    - In SMTP, the reliability of the sender information in emails is not implemented

Status Codes (Reply Codes) of SMTP Servers

- A SMTP server replies to a request with a three digit status/reply code and a short text which may vary or be omitted

Status code	Meaning	Description
2xx	**Success**	Command executed successfully
4xx	**Temporary failure**	Executing the command may be successful in the future
5xx	**Permanent failure**	Command can not be executed

- The table below contains some SMTP commands

Command	Function
`HELO`	Start SMTP session and identify client
`MAIL From:<...>`	Enter email address of the sender
`RCPT To:<...>`	Enter email address of the receiver
`DATA`	Enter Content of the email
`RSET`	Abort to enter an email
`NOOP`	No operation. Keeps the connection (avoids timeouts)
`QUIT`	Log out from the SMTP server

- Operating a SMTP server is risky because they lack security features
  - Additional software can improve the security of SMTP servers (e.g. S/MIME for signatures, SSL/TLS for encryption)

Popular SMTP servers are among others Exim, IBM Lotus Domino, MS Exchange, Postfix and Sendmail

Sending Emails via SMTP with Telnet

```
$ telnet sushi.unix-ag.uni-kl.de 25
Trying 2001:638:208:ef34:0:ff:fe00:65...
Connected to sushi.unix-ag.uni-kl.de.
Escape character is '^]'.
220 sushi.unix-ag.uni-kl.de ESMTP Sendmail 8.14.3/8.14.3/Debian-5+lenny1; Mon, 5 Sep...
HELO sushi
250 sushi.unix-ag.uni-kl.de Hello sushi.unix-ag.uni-kl.de, pleased to meet you
MAIL FROM:<cray@unix-ag.uni-kl.de>
250 2.1.0 <cray@unix-ag.uni-kl.de>... Sender ok
RCPT TO:<wolkenrechnen@gmail.com>
250 2.1.5 <wolkenrechnen@gmail.com>... Recipient ok
DATA
354 Enter mail, end with "." on a line by itself
From: <cray@unix-ag.uni-kl.de>
To: <wolkenrechnen@gmail.com>
Subject: Testmail
Date: Mon, 5 Sep 2011 11:49:50 +200

This is a test mail.
.
250 2.0.0 p859lbSc018528 Message accepted for delivery
QUIT
221 2.0.0 sushi.unix-ag.uni-kl.de closing connection
Connection closed by foreign host.
```

With encryption (TLS): `openssl s_client -starttls smtp -connect <server>:587`
With encryption (SSL): `openssl s_client -connect <server>:465`

Post Office Protocol (POP)

- Protocol (RFC 918), which allows to list, fetch and delete emails from an email server
- Uses TCP (default port: 110)
- Latest version is version 3 (POP3) from 1988 (RFC 1081 and 1939)
- The entire communication is transmitted in plain text
- Because POP3 is a text-based protocol, it is possible to connect via telnet to a POP3 server and list, fetch and delete emails *manually*

List, Fetch and Delete Emails via Telnet (1/2)

Command	Function
`USER xxx`	Enter username
`PASS xxx`	Enter password
`STAT`	Print the total number of emails in the mailbox and the total size (in bytes)
`LIST (n)`	Print the message numbers and size of all emails or of a specific email
`RETR n`	Print a specific email from the server
`DELE n`	Erase a specific email from the server
`RSET`	Reset all `DELE` commands
`NOOP`	No operation. Keeps the connection (avoids timeouts)
`QUIT`	Disconnect from the server and execute the `DELE` commands

```
$ telnet pop.gmx.com 110
Trying 212.227.17.187...
Connected to pop.gmx.com.
Escape character is '^]'.
+OK POP server ready H migmx001
USER christianbaun@gmx.de
+OK password required for user "christianbaun@gmx.de"
PASS xyz
+OK mailbox "christianbaun@gmx.de" has 2 messages (6111 octets) H migmx107
STAT
+OK 2 6111
LIST
+OK
1 4654
2 1457
```

List, Fetch and Delete Emails via Telnet (2/2)

```
RETR 2
+OK
Return-Path: <wolkenrechnen@gmail.com>
Delivered-To: GMX delivery to christianbaun@gmx.de
...
From: Christian Baun <wolkenrechnen@gmail.com>
To: christianbaun@gmx.de
Subject: Testmail
Date: Mon, 5 Sep 2011 15:33:39 +0200
User-Agent: KMail/1.13.5 (Linux/2.6.35-30-generic; KDE/4.5.5; i686; ; )
MIME-Version: 1.0
Content-Type: Text/Plain;
  charset="us-ascii"
Content-Transfer-Encoding: 7bit
...

This is a test mail.
.
DELE 2
+OK
QUIT
+OK POP server signing off
Connection closed by foreign host.
```

With encryption (POP3S): `openssl s_client -connect <server>:995`