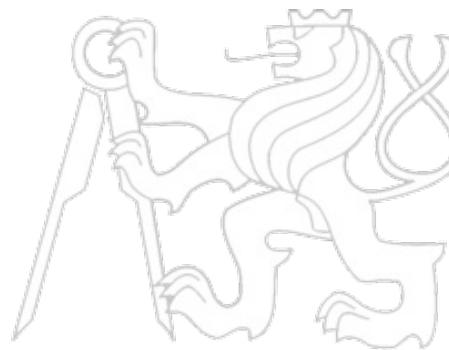


Middleware Architectures 1

Lecture 6: Communication Protocols

doc. Ing. Tomáš Vitvar, Ph.D.

tomas@vitvar.com • @TomasVitvar • <https://vitvar.com>



Czech Technical University in Prague

Faculty of Information Technologies • Software and Web Engineering • <https://vitvar.com/lectures>



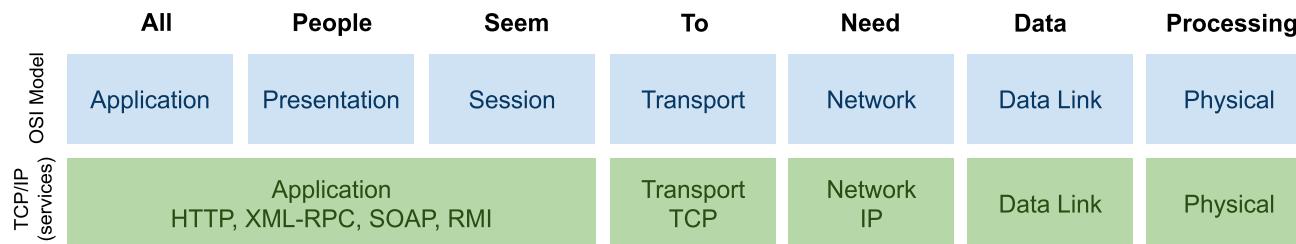
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Overview

- Introduction to Application Protocols
- Hypertext Transfer Protocol (HTTP)
- Security

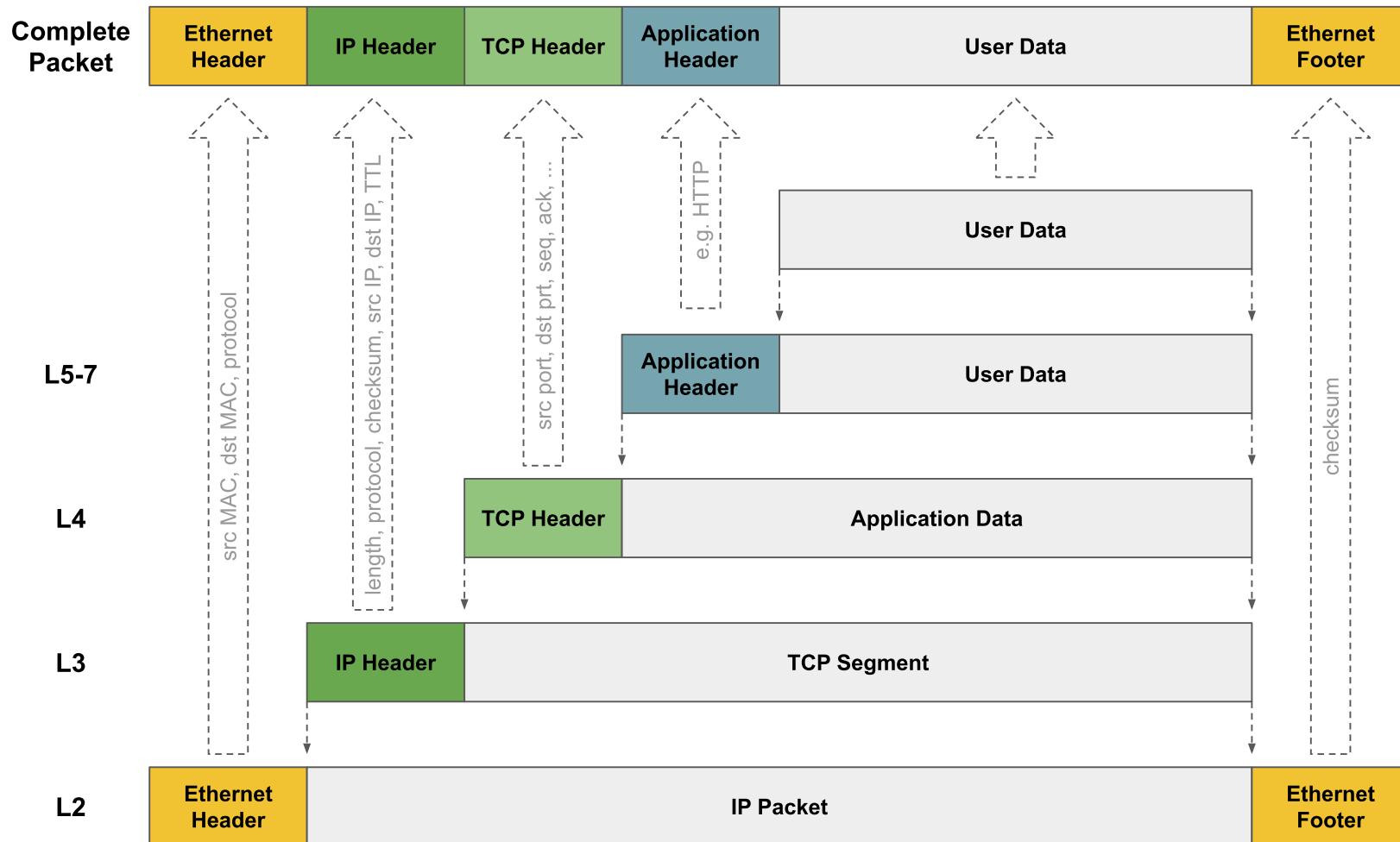
Application Protocols

- Remember this

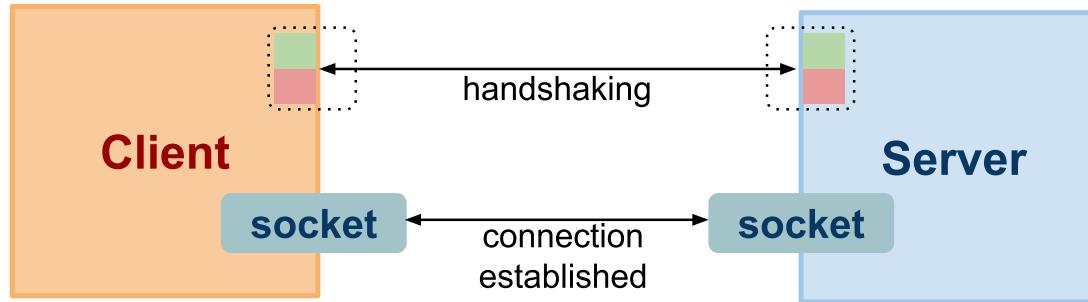


- App protocols mostly on top of the TCP Layer
 - *use TCP socket for communication*
- Major protocols
 - *HTTP – most of the app protocols layered on HTTP*
 - *HTTP/2 – new binary framing*
 - *gRPC – modern RPC protocol on top of HTTP/2*
 - *WebSocket – new protocol part of HTML5*
- Legacy
 - *RMI – Remote Method Invocation*
→ *Java-specific; vendor-interoperability problem*
 - *XML-RPC and SOAP – Remote Procedure Call and SOAP*

Anatomy of a Packet



Socket



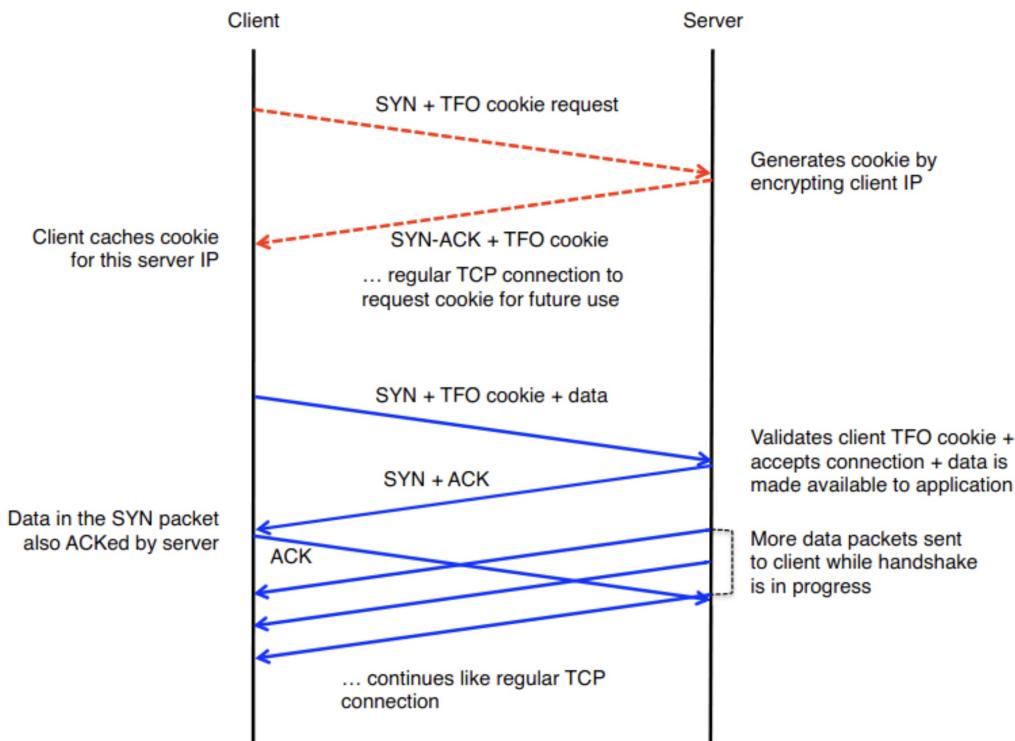
- Handshaking (connection establishment)
 - *The server listens at [dst_ip, dsp_port]*
 - *Three-way handshake:*
 - *the client sends a connection request with TCP flags (SYN, x=rand)*
 - *the server responds with its own TCP flags (SYN ACK, x+1 y=rand)*
 - *the client acknowledges the response, can send data along (ACK, y+1 x+1)*
 - *Result is a socket (virtual communication channel) with unique identification:*
 $\text{socket} = [\text{src_ip}, \text{src_port}; \text{dst_ip}, \text{dst_port}]$
- Data transfer (resource usage)
 - *Client/server writes/reads data to/from the socket*
 - *TCP features: reliable delivery, correct order of packets, flow control*
- Connection close

New Connection Costs

- Creating a new TCP connection is expensive
 - *It requires to complete a full roundtrip*
 - *It is limited by a network latency, not bandwidth*
- Example
 - *Distance from London to New York is approx. 5500 km*
 - *Communication over a fibre link will take at least 28ms one way*
 - *Three-way handshake will take a minimum of 56ms*
- Connection reuse is critical for any app running over TCP
 - *HTTP Keep-alive*
 - *HTTP pipelining*

TCP Fast Open

- TFO allows to speed up the opening of successive TCP connections
 - *TCP cookie stored on the client that was established on initial connection*
 - *The client sends the TCP cookie with SYN packet*
 - *The server verifies the TCP cookie and can send the data without final ACK*
 - *Can reduce network transaction latency by 15%*



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Hypertext Transfer Protocol – HTTP

- Application protocol, basis of Web architecture
 - *Part of HTTP, URI, and HTML family*
 - *Request-response protocol*
- One socket for single request-response
 - *original specification*
 - *have changed due to performance issues*
 - *many concurrent requests*
 - *overhead when establishing same connections*
 - *HTTP 1.1 offers persistent connection and pipelining*
 - *Domain sharding*
- HTTP is stateless
 - *Multiple HTTP requests cannot be normally related at the server*
 - *"problems" with state management*
 - *REST goes back to the original HTTP idea*

HTTP Request and Response

- Request Syntax

```
method uri http-version <crlf>
(header : value <crlf>)*
<crlf>
[ data ]
```

- Response Syntax

```
http-version response-code [ message ] <crlf>
(header : value <crlf>)*
<crlf>
[ data ]
```

- Semantics of terms

```
method          = "GET" | "POST" | "DELETE" | "PUT" | "HEAD" | "OPTIONS"
uri            = [ path ] [ ";" params ] [ "?" query ]
http-version   = "HTTP/1.0" | "HTTP/1.1"
response-code  = valid response code
header : value = valid HTTP header and its value
data           = resource state representation (hypertext)
```

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Persistent connections

- Persistent HTTP connection = HTTP keepalive
 - *TCP established connection used for multiple requests/responses*
 - *Avoids TCP three-way handshake to be performed on every request*
 - *Reduces latency*
 - *FIFO queuing order on the client (request queuing)*
→ *dispatch first request, get response, dispatch next request*
- Example: **GET /html**, **GET /css**
 - *server processing time 40ms and 20ms respectivelly*
- Without HTTP keepalive
 - *three-way handshake 84ms before the data is received on the server*
 - *Response received at 152ms and 132ms respectivelly*
 - *The total time is 284ms*
- HTTP keepalive
 - *One TCP connection for both requests*
 - *In our example this will save one RTT, i.e. 56ms*

The total time will be 228ms

Persistent connections savings

- Each request needs
 - *Without keepalive, 2 RTT of latency*
 - *With keepalive, the first request needs 2 RTT, a following request needs 1 RTT*
- Savings for **N** requests: **(N-1) x RTT**
- Average value of **N** is 90 requests for a Web app
 - *Measured by HTTP Archive (<http://httparchive.org>) as of 2013*
 - *Average Web application is composed of 90 requests fetched from 15 hosts*
 - *HTML: 10 requests*
 - *Images: 55 requests*
 - *Javascript: 15 requests*
 - *CSS: 5 requests*
 - *Other: 5 requests*

HTTP pipelining

- Important optimization – response queuing
 - Allows to relocate FIFO queue from the client to the server
- Requests are pipelined one after another
 - This allows the server to process requests immediately one after another
 - This saves one request and response propagation latency
 - In our example, the total time will be 172ms
- Parallel processing of requests
 - In our example this saves another 20ms of latency
 - **Head of line blocking**
 - Slower response (css with processing time 20ms) must be buffered until the first response is generated and sent (no interleaving of responses)
- Issues
 - A single slow response blocks all requests behind it
 - Buffered (large or many) responses may exhaust server resources
 - A failed response may terminate TCP connection
 - A client must request all subsequent resources again (duplicate processing)
 - Some intermediaries may not support pipelining and abort connection
- HTTP pipelining support today is limited

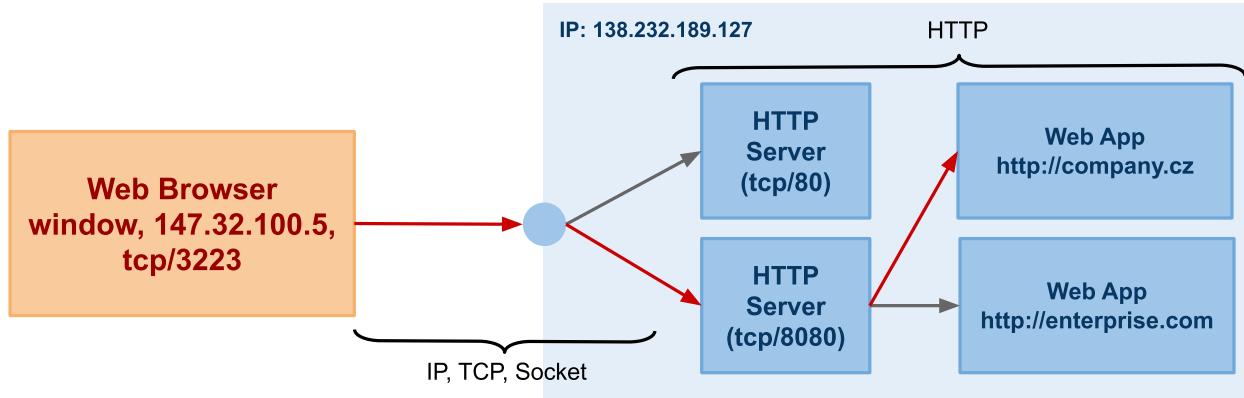
Multiple TCP connections

- Using only one TCP connection is slow
 - *Client must queue HTTP requests and process one after another*
- Multiple TCP connections work in parallel
- **There are 6 connections per host**
 - *The client can dispatch up to 6 requests in parallel*
 - *The server can process up to 6 requests in parallel*
 - *This is a trade-off between higher request parallelism and the client and server overhead*
- The maximum number of connections prevents from DoS attacks
 - *The client could exhaust server resources*
- Domain sharding
 - *The connection limit as per host (origin)*
 - *There can be multiple origins used in a page*
 - *Each origin has 6 maximum connection limit*
 - *A domain can be sharded*
 - **www.example.com** → **shard1.example.com**, **shard2.example.com**
 - *Each shard can resolve to the same IP or different IP, it does not matter*
 - *How many shards?*

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Serving HTTP Request



- Serving HTTP request
 1. User enters URL `http://shard1.example.com/orders` to the browser
 2. DNS resolution: browser gets an IP address for `shard1.example.com`
 3. Three-way handshake: browser and Web Server creates a socket
 4. Browser sends ACK and HTTP request:

```
1 | GET /orders HTTP/1.1
2 | Host: shard1.example.com
```
 5. Web server passes the request to the web application `shard1.example.com` which serves `GET orders` and that writes a response back to the socket.

Virtual Host

- Virtual host
 - Configuration of a named virtual host in a Web server
 - Web server uses host request header to distinguish among multiple virtual hosts on a single physical host.
- Apache virtual host configuration
 - Two virtual hosts in a single Web server

```
1 # all IP addresses will be used for named virtual hosts
2 NameVirtualHost *:80
3
4 <VirtualHost *:80>
5     ServerName www.example.com
6     ServerAlias shard1.example.com shard2.example.com
7     ServerAdmin admin@example.com
8     DocumentRoot /var/www/apache/example.com
9 </VirtualHost>
10
11 <VirtualHost *:80>
12     ServerName company.cz
13     ServerAdmin admin@firm.cz
14     DocumentRoot /var/www/apache/company.cz
15 </VirtualHost>
```

Overview

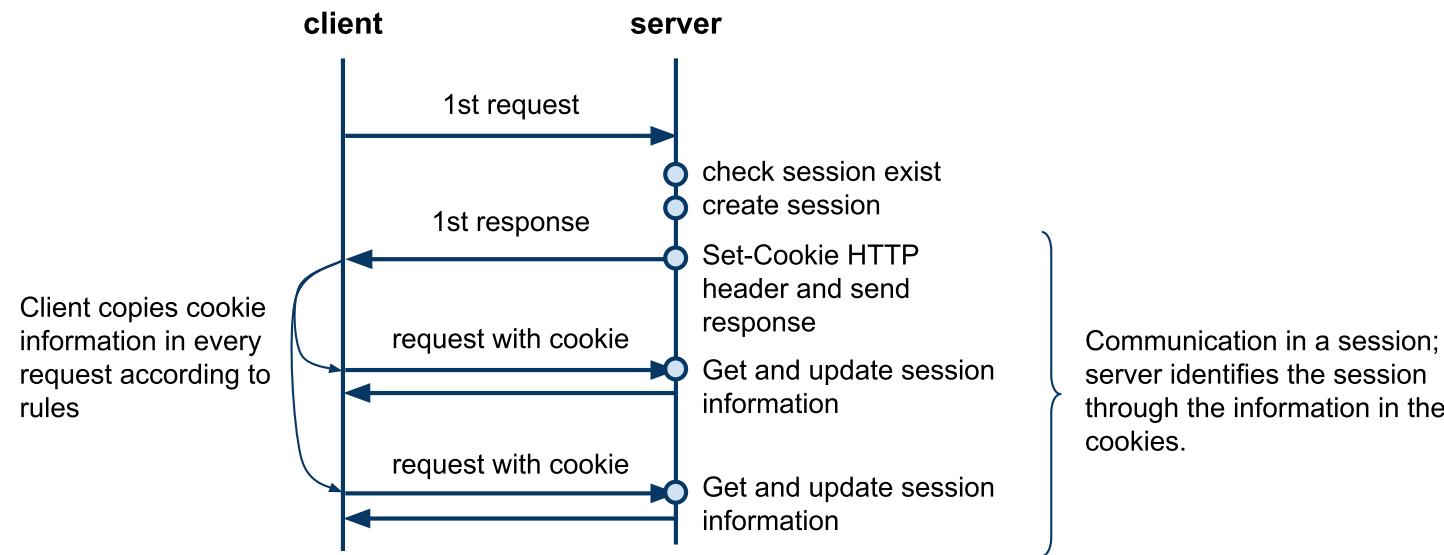
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State Management

- HTTP is a stateless protocol – original design
 - *No information to relate multiple interactions at server-side*
 - Except **Authorization** header is copied in every request
 - IP addresses do not work, one public IP can be shared by multiple clients
- Solutions to check for a valid state at server-side
 - **Cookies** – *obvious and the most common workaround*
 - RFC 2109 – *HTTP State Management Mechanism*
 - *Allow clients and servers to talk in a context called sessions*
 - **Hypertext** – *original HTTP design principle*
 - *App states represented by resources (hypermedia), links define transitions between states*
 - *Adopted by the REST principle statelessness*

Interaction with Cookies

- Request-response interaction with cookies
 - *Session is a logical channel maintained by the server*



- Stateful Server
 - *Server remembers the session information in a server memory*
 - *Server memory is a non-persistent storage, when server restarts the memory content is lost!*

Set-Cookie and Cookie Headers

- **Set-Cookie** response header

```
1 | set-cookie = "Set-Cookie:" cookie ("," cookie)*
2 |   cookie    = NAME "=" VALUE (";" cookie-av)*
3 |   cookie-av = "Comment" "=" value
4 |         | "Domain" "=" value
5 |         | "Max-Age" "=" value
6 |         | "Path" "=" value
```

- **domain** – a domain for which the cookie is applied
- **Max-Age** – number of seconds the cookie is valid
- **Path** – URL path for which the cookie is applied

- **Cookie** request header. A client sends the cookie in a request if:

- **domain** matches the origin server's fully-qualified host name
- **path** matches a prefix of the request-URI
- **Max-Age** has not expired

```
1 | cookie  = "Cookie:" cookie-value (";" cookie-value)*
2 |   cookie-value    = NAME "=" VALUE [";" path] [";" domain]
3 |   path            = "$Path" "=" value
4 |   domain          = "$Domain" "=" value
```

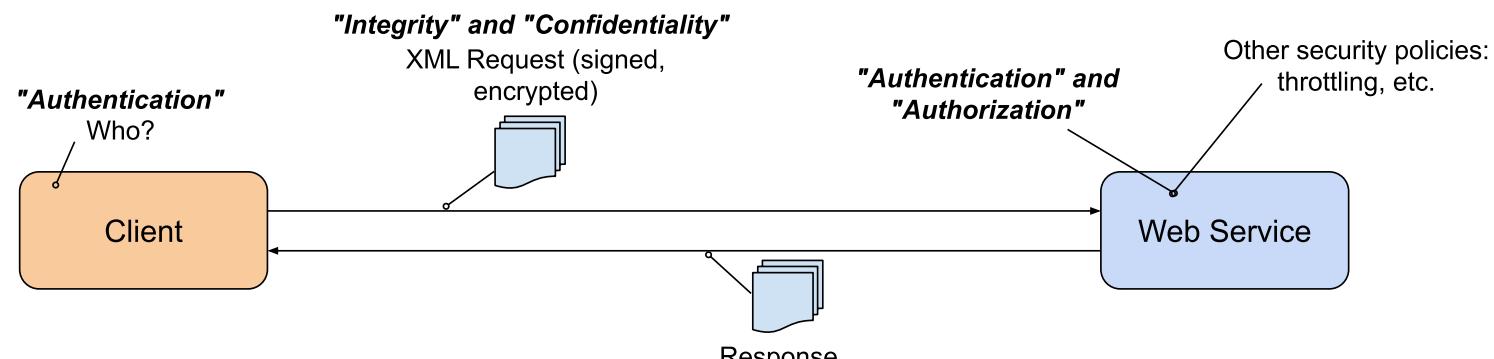
- **domain**, and **path** are values from corresponding attributes of the **Set-Cookie** header

Overview

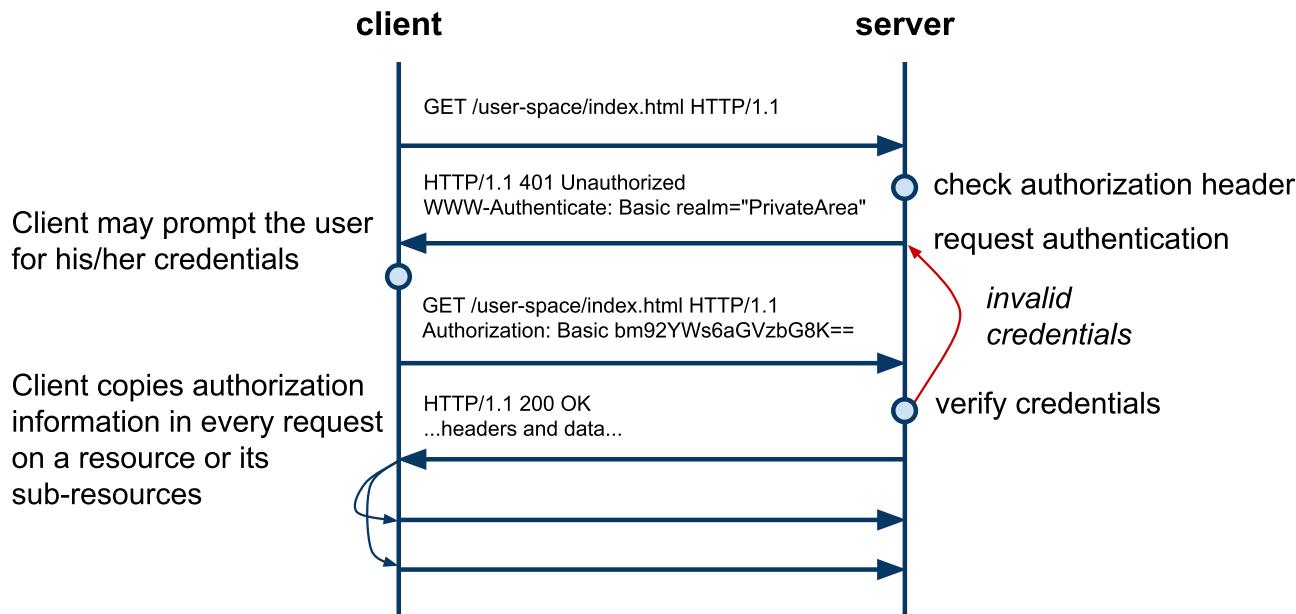
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Web Service Security Concepts

- Securing the client-server communication
 - *Message-level security*
 - *Transport-level security*
- Ensure
 - *Authentication* – verify a client's identity
 - *Authorization* – rights to access resources
 - *Message Confidentiality* – keep message content secret
 - *Message Integrity* – message content does not change during transmission
 - *Non-repudiation* – proof of integrity and origin of data



Basic Access Authentication



- **Realm**

- *an identifier of the space on the server (~ a collection of resources and their sub-resources)*
- *A client may associate valid credentials with realms such that it copies authorization information in requests for which server requires authentication (by **WWW-Authenticate** header)*

Basic Access Authentication – Credentials

- Credentials
 - *credentials are base64 encoded*
 - *the format is: username:password*

```
1 # to encode in linux
2 echo "novak:heslo" | base64
3 > bm92YWs6aGVzbG8K
4
5 # and to decode
6 echo "bm92YWs6aGVzbG8K" | base64 -d # use capital "D" in OS X
7 > novak:heslo
```

- Comments
 - *When TLS is not used, the password can be read*
 - *An attacker can repeat interactions*

Digest Access Authentication

- RFC 2617 – Basic and Digest Access Authentication
 - No password between a client and a server but a hash value
 - Simple and advanced mechanisms (only server-generated nonce value – replay-attacks or with client-generated nonce value)
- Basic Steps

1. Client accesses a protected area

```
1 | > GET / HTTP/1.1
```

2. Server requests authentication with **WWW-Authenticate**

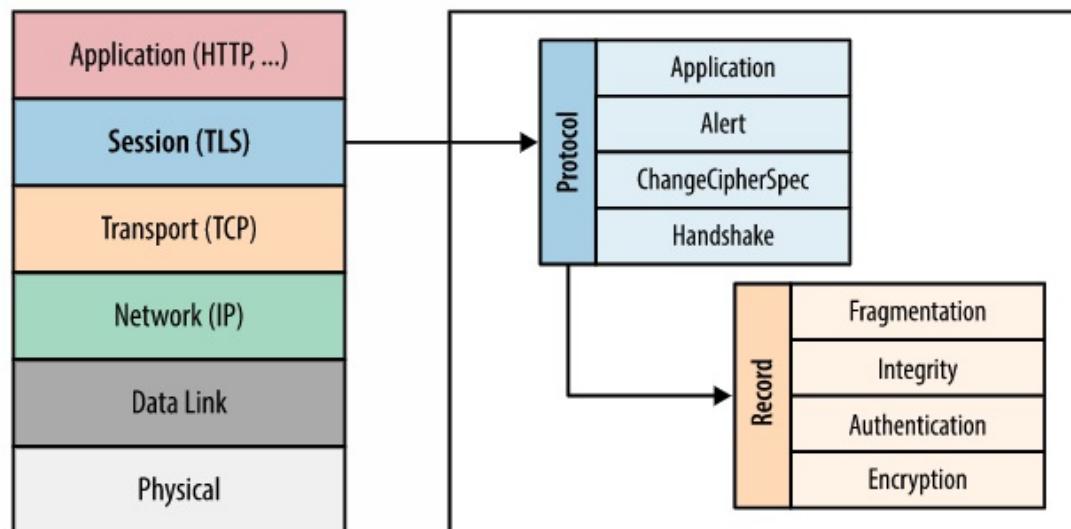
```
1 | < HTTP/1.1 401 Unauthorized
2 | < WWW-Authenticate: Digest realm="ProtectedArea",
3 |   nonce="BbdQof3DBAA=a293ff3d724989371610f03015f2d23f3cd2c045",
4 |   algorithm=MD5, domain="/", qop="auth"
```

3. Client calculates a response hash by using the realm, his/her username, the password, and the quality of protection (QoP) and requests the resource with **authorization** header

```
1 | > GET / HTTP/1.1
2 | > Authorization: Digest username="novak", realm="ProtectedArea",
3 |   nonce="BbdQof3DBAA=a293ff3d724989371610f03015f2d23f3cd2c045", uri="/",
4 |   algorithm=MD5, response="c4ea2293aeb318826d1e533f363efd90", qop=auth,
5 |   nc=00000001, cnonce="531ee8ba7f2a8fd1"
```

Transport Level Security

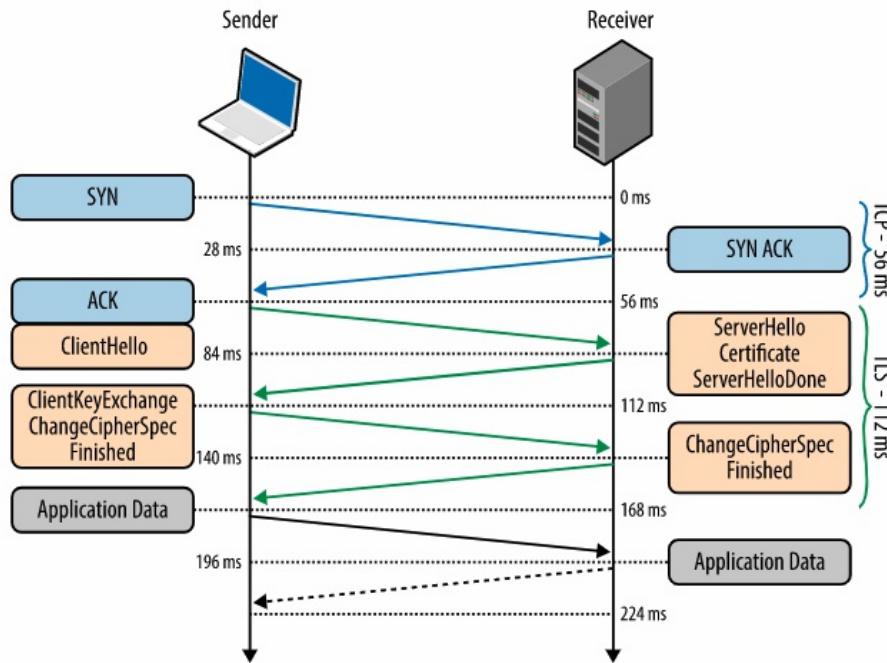
- SSL and TLS
 - *SSL and TLS is used interchangeably*
 - *SSL 3.0 developed by Netscape*
 - *IETF standardization of SSL 3.0 is TLS 1.0*
→ *TLS 1.0 is upgrade of SSL 3.0*
 - *Due to security flaws in TLS 1.0, TLS 1.1 and TLS 1.2 were created*
- TLS layer



TLS Services

- Encryption
 - Peers must agree on ciphersuite and keys
 - This is achieved by **TLS handshake**
- Authentication
 - Peers can authenticate their identity
 - The client can verify that the server is who it is claimed to be
 - Achieved by "Chain of Trust and Certificate Authoritites"
 - The server can also verify the client
- Integrity
 - TLS provides message framing mechanism
 - Every message is signed with Message Authentication Code (MAC)
 - MAC hashes data in a message and combines the resulting hash with a key (negotiated during the TLS handshake)
 - The result is a message authentication code sent with the message

TLS Handshake Protocol



- TLS Handshake

56 ms: *ClientHello, TLS protocol version, list of ciphersuites, TLS options*

84 ms: *ServerHello, TLS protocol version, ciphersuite, certificate*

112 ms: *RSA or Diffie-Hellman key exchange*

140 ms: *Message integrity checks, sends encrypted "Finished" message*

168 ms: *Decrypts the message, app data can be sent*

Key Exchange

- RSA key exchange(Rivest–Shamir–Adleman)
 - *The client generates a symmetric key*
 - *The client encrypts the key with the server's public key*
 - *The client sends the encrypted key to the server*
 - *The server uses its private key to decrypt the symmetric key*
- RSA critical weakness
 - *The same public-private key pair is used to:*
 - *authenticate the server (the server's private key is used to sign and verify the handshake)*
 - *encrypt the symmetric key*
 - *When an attacker gets hold of the server private key*
 - *It can decrypt the entire session*
- Diffie-Hellman key exchange
 - *Client and server can negotiate shared secret without its explicit communication*
 - *Attacker cannot get the key*
 - *Reduction of risk of compromising of the past communications*
 - *New key can be generated as part of every key exchange*
 - *Old keys can be discarded*

TLS and Proxy Servers

- TLS Offloading
 - *Inbound TLS connection, plain outbound connection*
 - *Proxy can inspect messages*
- TLS Bridging
 - *Inbound TLS connection, new outbound TLS connection*
 - *Proxy can inspect messages*
- End-to-End TLS (TLS pass-through)
 - *TLS connection is passed-through the proxy*
 - *Proxy cannot inspect messages*
- Load balancer
 - *Can use TLS offloading or TLS bridging*
 - *Can use TLS pass-through with help of Server Name Indication (SNI)*