

# Middleware Architectures 1

## Lecture 6: Communication Protocols

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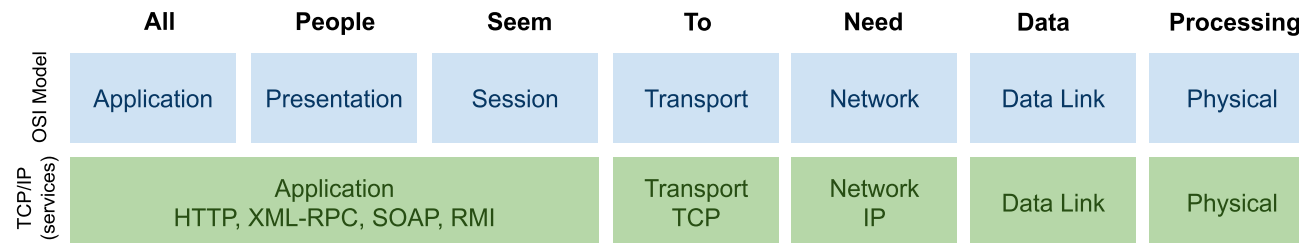
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# Overview

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

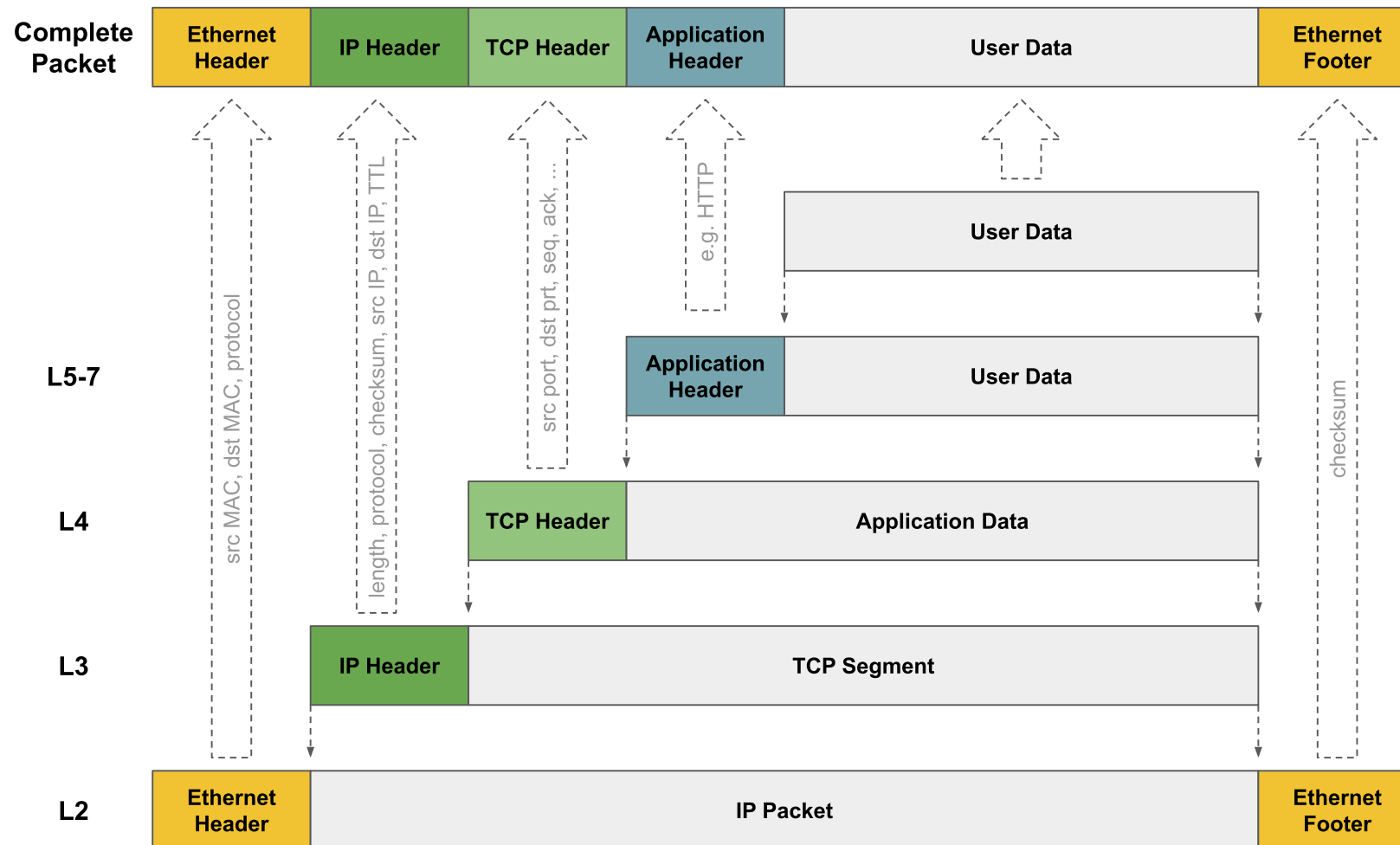
# Application Protocols

- Remember this

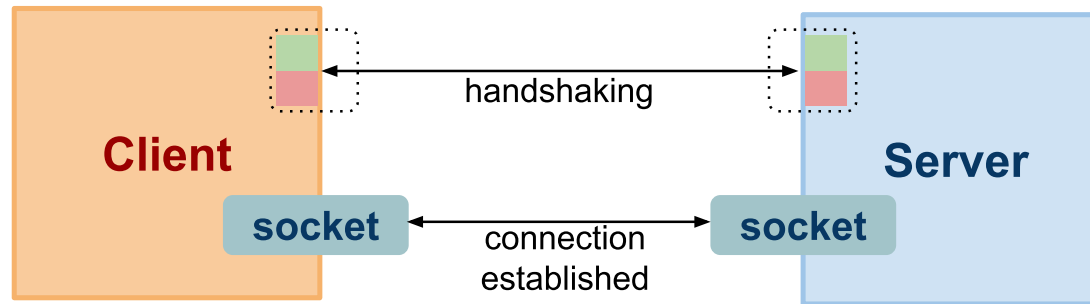


- App protocols mostly on top of the TCP Layer
  - *use TCP socket for communication*
- Major protocols
  - *HTTP – most of the app protocols layered on HTTP*
  - *HTTP/2 – new binary framing*
  - *gRPC – modern RPC protocol on top of HTTP/2*
  - *WebSocket – new protocol part of HTML5*
- Legacy
  -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

# Anatomy of a Packet



# Socket



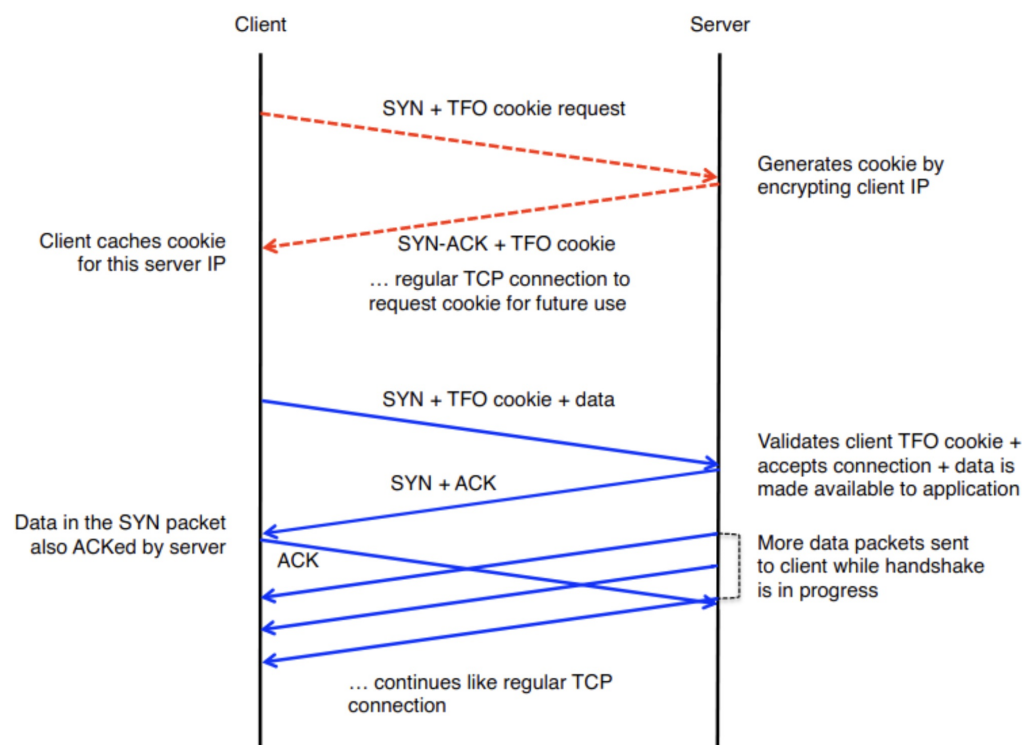
- Handshaking (connection establishment)
  - The server listens at `[dst_ip, dsp_port]`
  - Three-way handshake:
    - the client sends a connection request with TCP flags (SYN,  $x=rand$ )
    - the server responds with its own TCP flags (SYN ACK,  $x+1$   $y=rand$ )
    - the client acknowledges the response, can send data along (ACK,  $y+1$   $x+1$ )
  - Result is a socket (virtual communication channel) with unique identification:  
`socket=[src_ip,src_port;dst_ip,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%*



# Overview

- Introduction to Application Protocols
- **Hypertext Transfer Protocol (HTTP)**
  - *Performance*
  - *Configuration*
  - *State Management*
- Security



# 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 respectively*
- Without HTTP keepalive
  - *three-way handshake 84ms before the data is received on the server*
  - *Response received at 152ms and 132ms respectively*
  - *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:  **$(N-1) \times \text{RTT}$**
- 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 relegate 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 sub-sequent resources again (duplicate processing)*
  - *Some intermediaries may not support pipelining and abort connection*
- HTTP pipelining support today is limited

# Multiple TCP connections

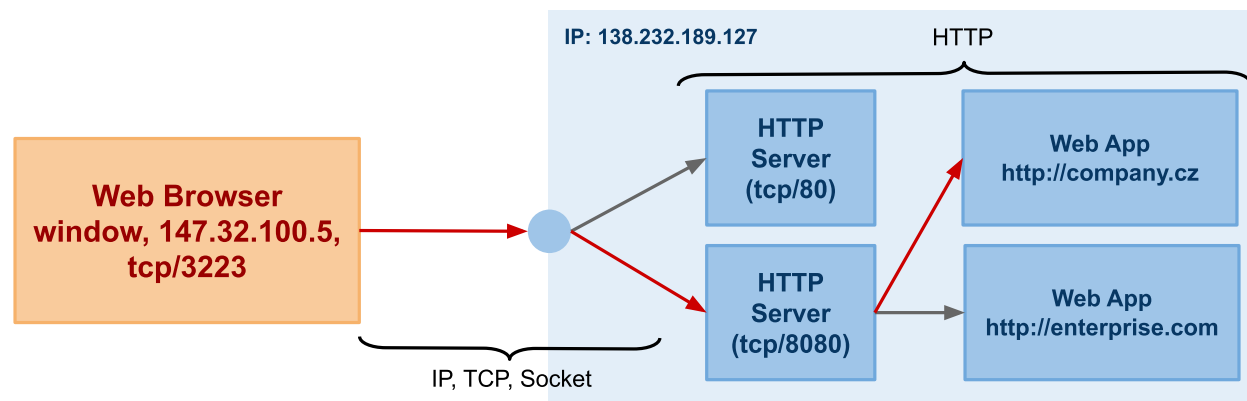
- Using only one TCP connection is slow
  - *Client must queue HTTP requests and process one after another*
- Multiple TCP connections work in parallel
- **There are 6 connections per host**
  - *The client can dispatch up to 6 requests in parallel*
  - *The server can process up to 6 requests in parallel*
  - *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

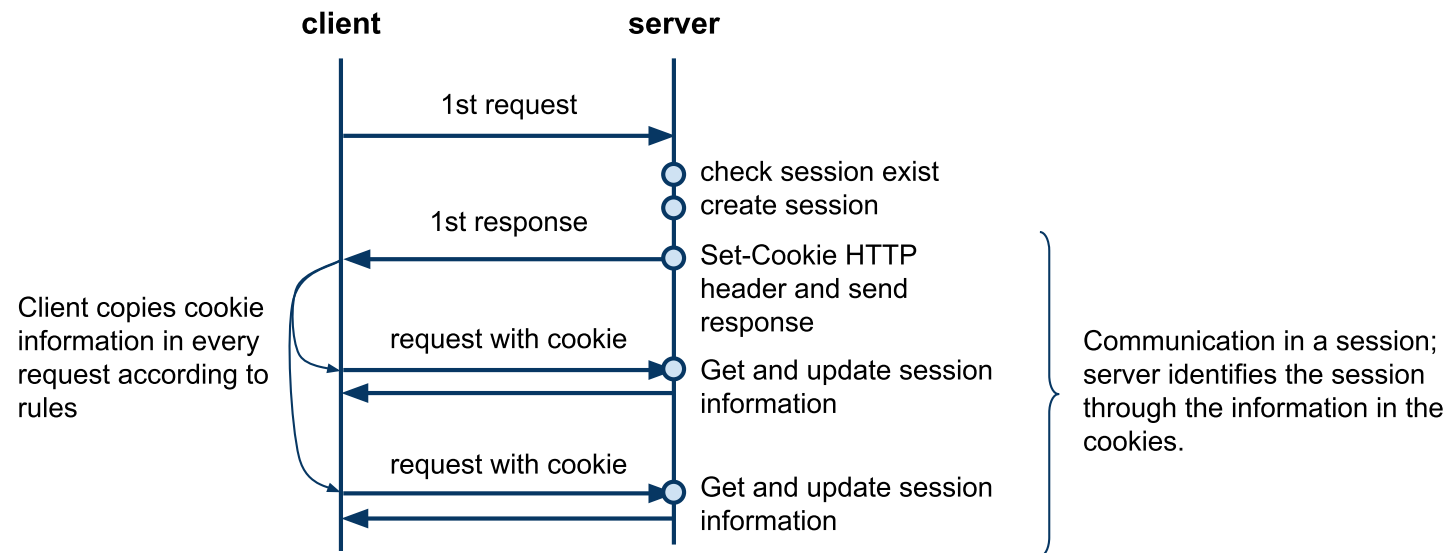
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# State Management

- 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
```

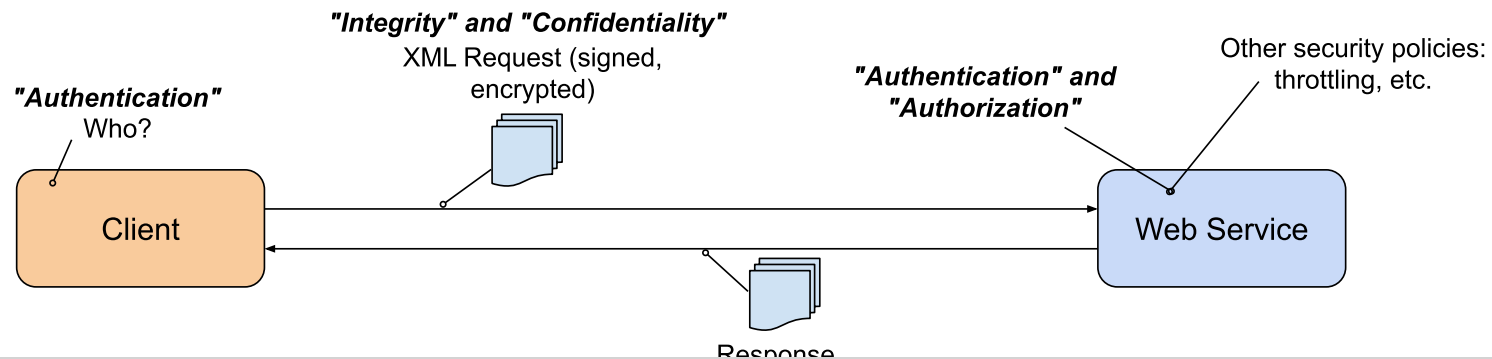
- **domain**, and **path** *are values from corresponding attributes of the Set-Cookie header*

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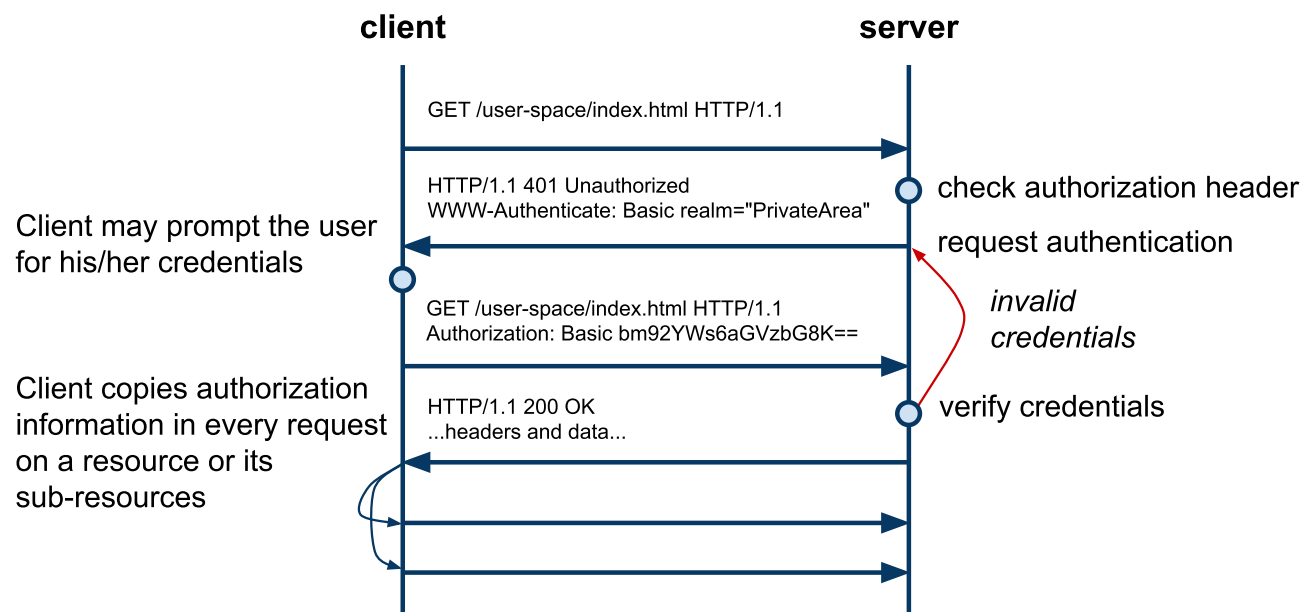
# Web Service Security Concepts

- 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 a 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*

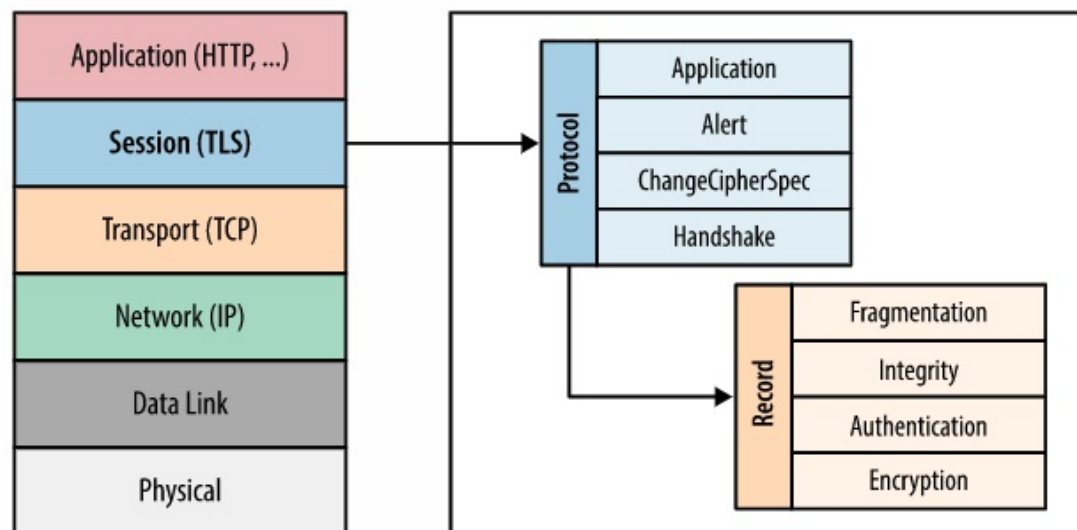
```
1 | < HTTP/1.1 401 Unauthorized
2 | < WWW-Authenticate: Digest realm="ProtectedArea",
3 |   nonce="BbdQof3DBAA=a293ff3d724989371610f03015f2d23f3cd2c045",
4 |   algorithm=MD5, domain="/", qop="auth"
```

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

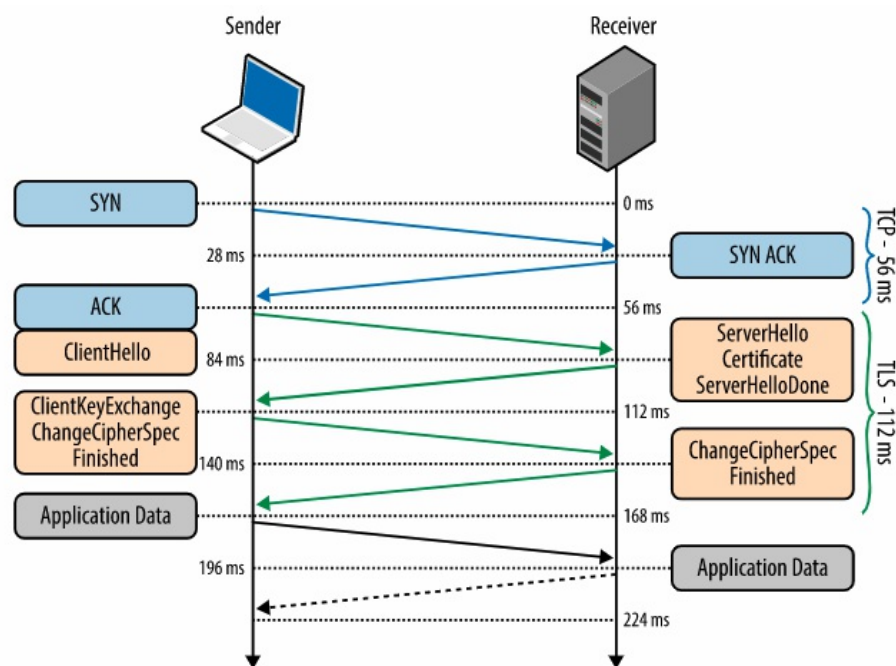
- SSL and TLS
  - *SSL and TLS is used interchangeably*
  - *SSL 3.0 developed by Netscape*
  - *IETF standardization of SSL 3.0 is TLS 1.0*
    - *TLS 1.0 is upgrade of SSL 3.0*
  - *Due to security flaws in TLS 1.0, TLS 1.1 and TLS 1.2 were created*
- TLS layer



# 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 Authorities"*
    - *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)*