Middleware Architectures 1

Lecture 3: 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

Modified: Mon Sep 22 2025, 10:19:11
Humla v1.0

Overview

- Introduction to Application Protocols
- Introduction to HTTP
- Security

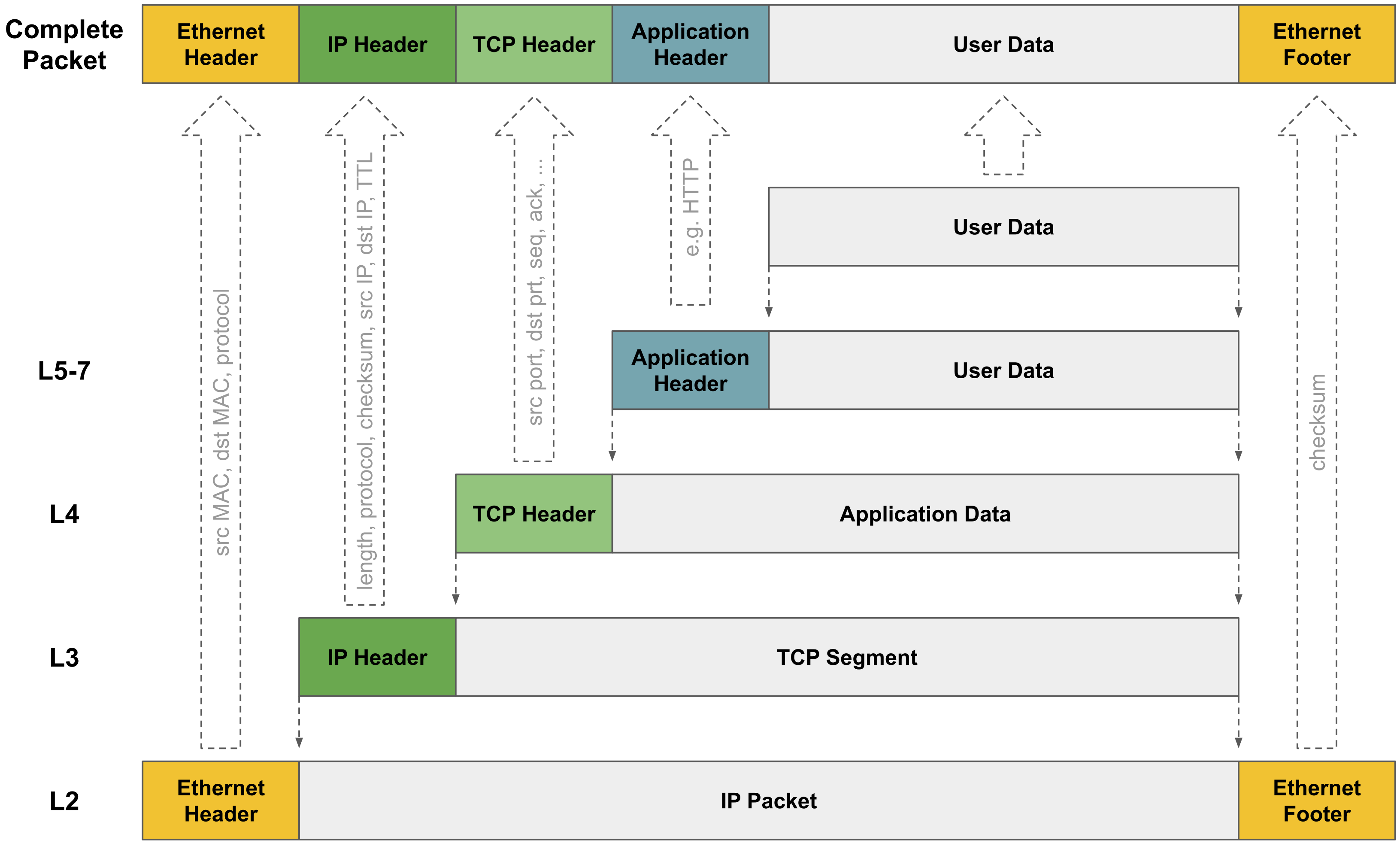
Application Protocols

- Remember this

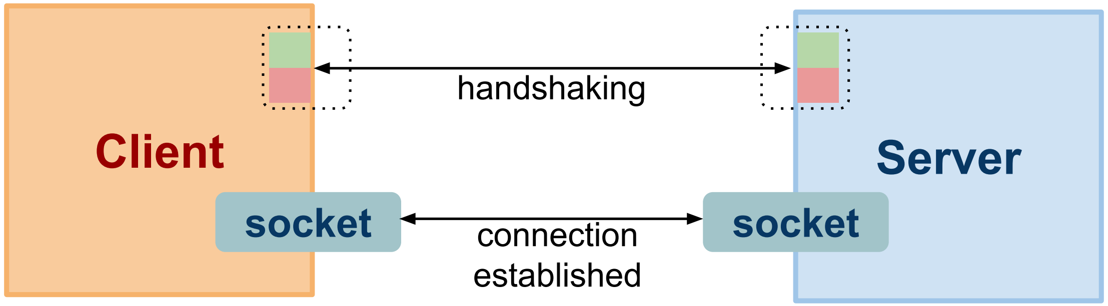
	All	People	Seem	To	Need	Data	Processing
OSI Model	Application	Presentation	Session	Transport	Network	Data Link	Physical
TCP/IP (services)	Application HTTP, XML-RPC, SOAP, RMI			Transport TCP	Network IP	Data Link	Physical

- 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*
    - *→ widely spread*
  - *RMI – Remote Method Invocation*
    - *→ Java-specific; vendor-interoperability problem*
    - *→ may use HTTP underneath (among other things)*
  - *XML-RPC and SOAP – Remote Procedure Call and SOAP*
    - *→ HTTP-based*
  - *WebSocket – new protocol part of HTML5*

Anatomy of a Packet



Socket

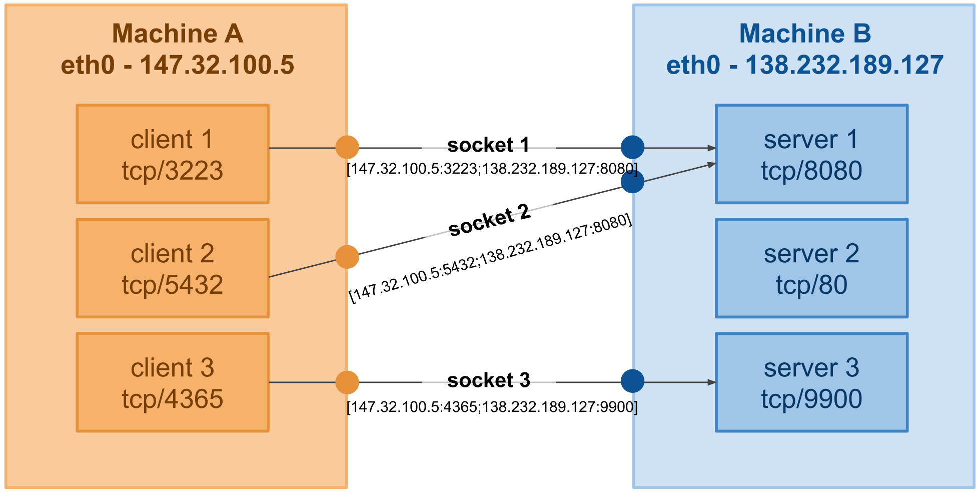


- Handshaking (connection establishment)
  - *The server listens at* `[dst_ip,dsp_port]`
  - *Three-way handshake:*
    - → *the client sends a connection request with TCP flags (SYN, x=rand)*
    - → *the server respons with its own TCP flags (SYN ACK, x+1 y=rand)*
    - → *the client acknowledges the 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 handskake 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)
  - *TFO allows to speed up the opening of successfive 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%*
  - *TFO is supported by Linux in 3.7+ kernels*

Addressing in Application Protocol



- IP addressing: IP is an address of a machine interface
  - *A machine can have multiple interfaces (eth0, eth1, bond0, ...)*
- TCP addressing: TCP port is an address of an app running on a machine and listening on a machine interface
  - *Multiple applications with different TCP ports may listen on a machine interface*
- Application addressing
  - *Additional mechanisms to address entities within an application*
  - *They are out of scope of IP/TCP, they are app specific*
    → for example, Web apps served by a single Web server

Overview

- Introduction to Application Protocols
- Introduction to HTTP
  - *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)
```

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 reuqests*
    - → *Images: 55 requests*
    - → *Javascript: 15 requests*
    - → *CSS: 5 requests*
    - → *Other: 5 requests*

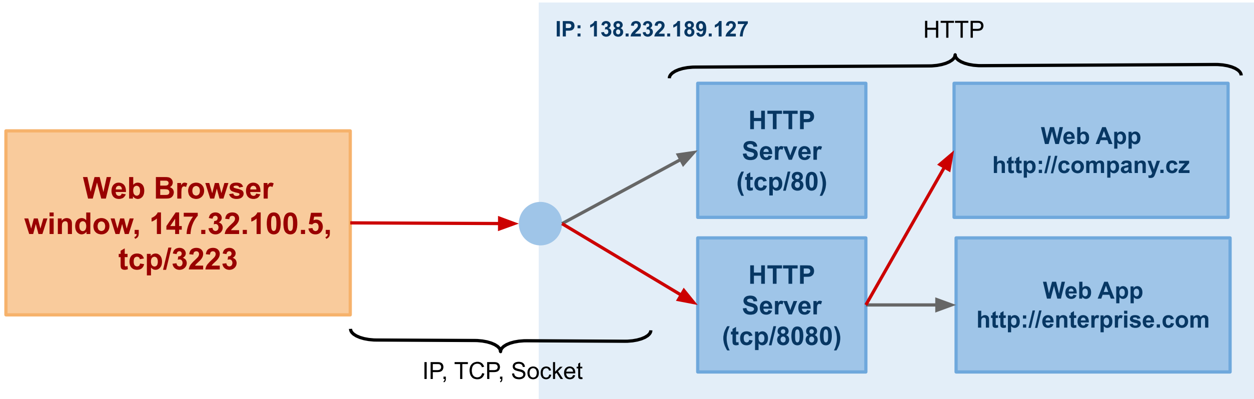
HTTP pipelining

- Important optimization – response queuing
  - *Allows to relecote FIFO queue from the client to the server*
- Requests are pipelined one after another
  - *This allows the server to process requests immediatelly 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 (dupplicate 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 paralellism 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?*

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:*

```
GET /orders HTTP/1.1
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*

```
# all IP addresses will be used for named virtual hosts
NameVirtualHost *:80

<VirtualHost *:80>
        ServerName www.example.com
        ServerAlias shard1.example.com shard2.example.com
        ServerAdmin admin@example.com
        DocumentRoot /var/www/apache/example.com
</VirtualHost>

<VirtualHost *:80>
        ServerName company.cz
        ServerAdmin admin@firm.cz
        DocumentRoot /var/www/apache/company.cz
</VirtualHost>
```

Better Support for HTTP Testing

- Use `curl` to test HTTP protocol

```
Usage: curl [options...] <url>

-X/--request <command>          Specify request command to use
-H/--header <line>              Custom header to pass to server
-d/--data <data>                HTTP POST data
-b/--cookie <name=string/file>  Cookie string or file to read cookies from
-v/--verbose                    Make the operation more talkative
```

- Example

```
curl -v -H "Host: company.cz"  127.0.0.1:8080

* About to connect() to 127.0.0.1 port 8080
*   Trying 127.0.0.1... connected
* Connected to 127.0.0.1 port 8080
> GET / HTTP/1.1
> User-Agent: curl/7.20.0 (i386-apple-darwin10.3.2) libcurl/7.20.0 OpenSSL/0.9.8n
> Accept: */*
> Host: company.cz
>
< HTTP/1.1 201 OK
< Connection: keep-alive
< Content-Type: plain/text
<
< This is the response...
```

Overview

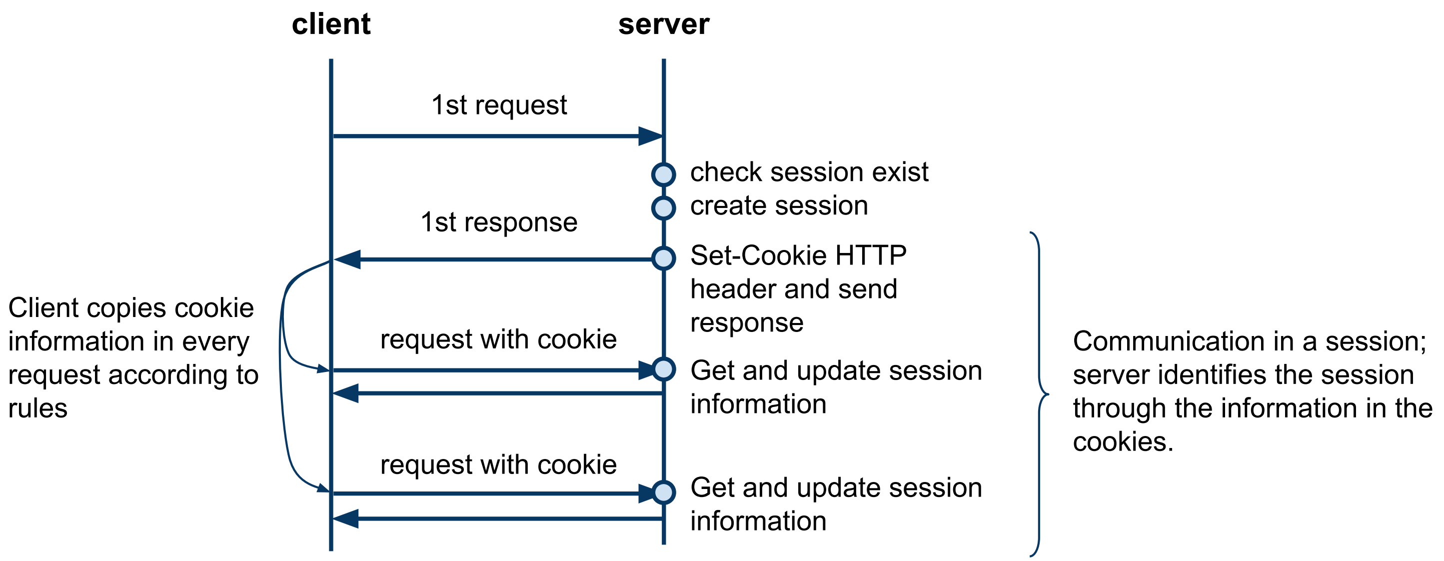
- Introduction to Application Protocols
- Introduction to HTTP
  - *State Management*
- Security

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

```
set-cookie = "Set-Cookie:" cookie ("," cookie)*
  cookie     = NAME "=" VALUE (";" cookie-av)*
  cookie-av = "Comment" "=" value
             | "Domain" "=" value
             | "Max-Age" "=" value
             | "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*

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

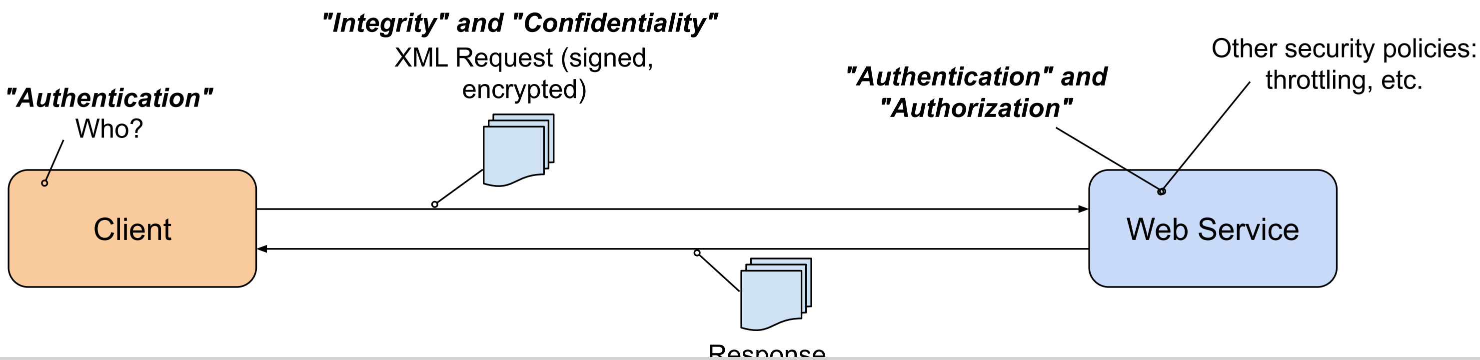
  – `domain`, *and* `path` *are values from corresponding attributes of the* `Set-Cookie` *header*

Overview

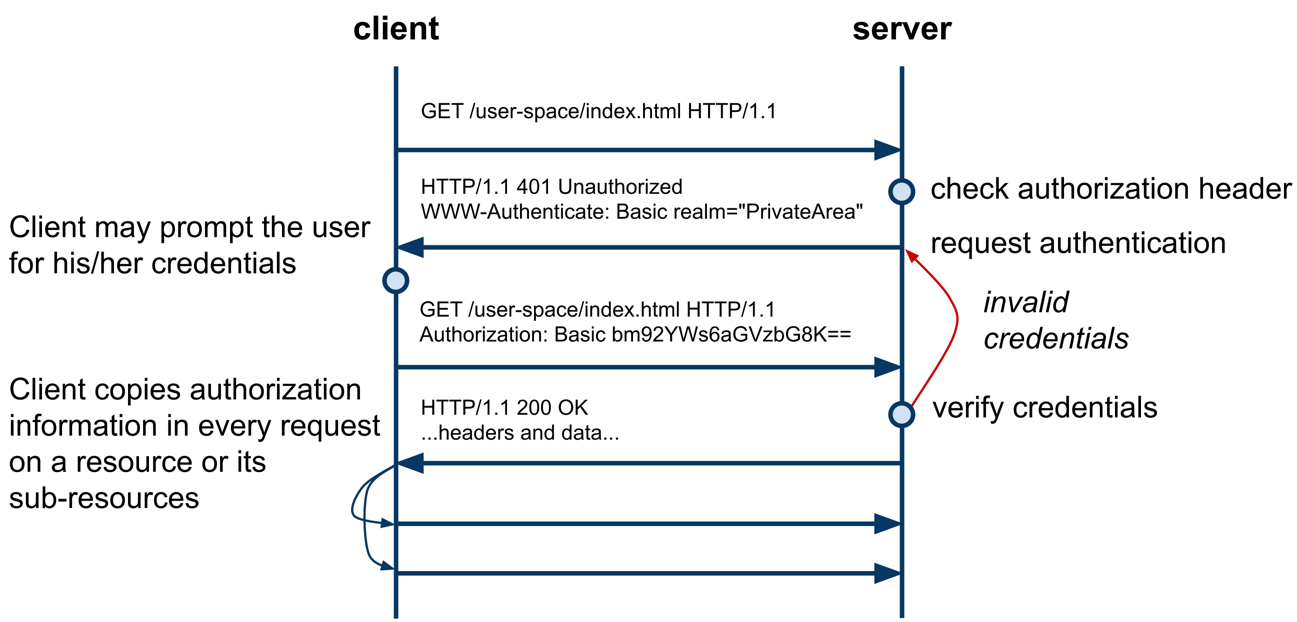
- Introduction to Application Protocols
- Introduction to HTTP
- Security

Web Service Security Concepts

- Securing the client-server communcation
  - *Message-level security*
  - *Transport-level security*
- Ensure
  - *Authentication – verify a client's identity*
  - *Authorizaton – 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`

```
# to encode in linux
echo "novak:heslo" | base64
> bm92YWs6aGVzbG8K

# and to decode
echo "bm92YWs6aGVzbG8K" | base64 -d # use capital "D" in OS X
> 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*

     ```
     > GET / HTTP/1.1
     ```

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

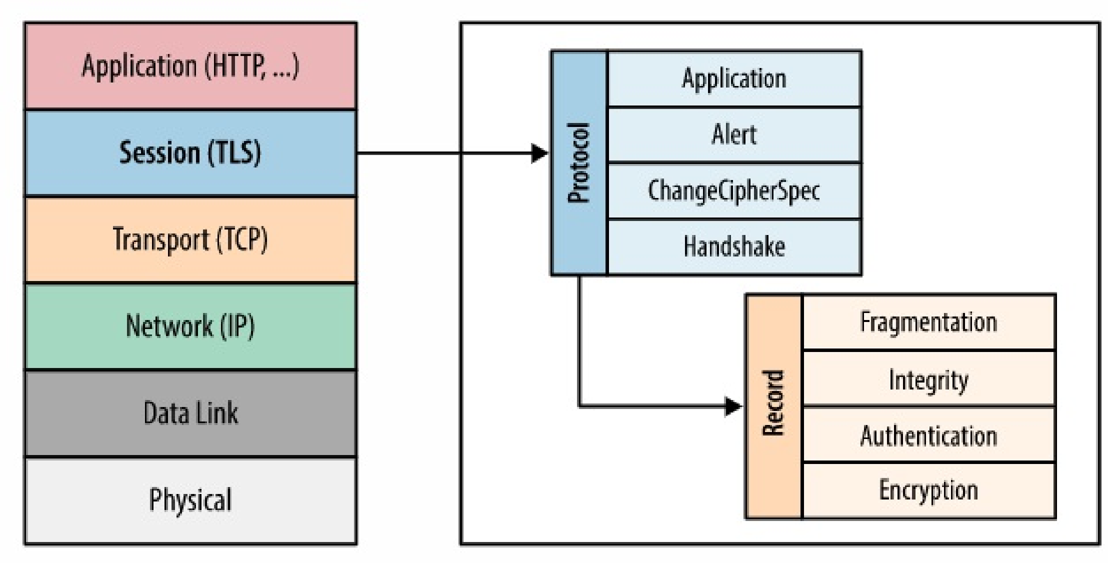
     ```
     < HTTP/1.1 401 Unauthorized
     < WWW-Authenticate: Digest realm="ProtectedArea",
       nonce="BbdQof3DBAA=a293ff3d724989371610f03015f2d23f3cd2c045",
       algorithm=MD5, domain="/", qop="auth"
     ```

  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*

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

Transport Level Security

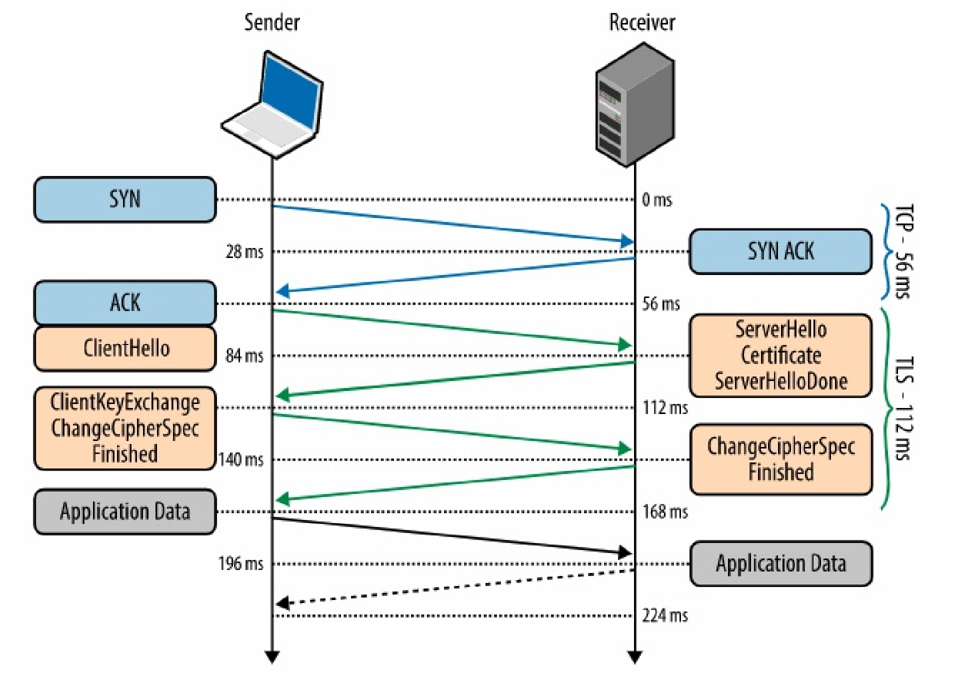
- SSL and TLS
  - *SSL and TLS is used interchangeably*
  - *SSL 3.0 developed by Netscape*
  - *IETF standardization of SSL 3.0 is TLS 1.0*
    $\rightarrow$ *TLS 1.0 is upgrade of SSL 3.0*
  - *Due to security flaws in TLS 1.0, TLS 1.1 and TLS 1.2 were created*
- TLS layer



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 provives 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 exhange(Rivest–Shamir–Adleman)
  - *The client generates a symetric key*
  - *The client encrypts the key with the server's public key*
  - *The client sends the encrpyed key to the server*
  - *The server uses its private key to decrypt the symetric key*
- RSA critical weekness
  - *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 symetric key*
  - *When an attacker gets hold of the server private key*
    - → *It can decrypt the entire session*
- Diffie-Hellman key exhange
  - *Client and server can negoriate 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)*