Web Sockets

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Outline

- What are WebSockets
- Why arose?
- How implemented?
- Implications on SOP and CORS
- Vulnerabilities
- Defenses
- Real Life Examples
- Summary and References

Web Sockets

- Standardized by Internet Engineering Task Force (IETF) in 2011
- A new protocol that operates at application layer (much like HTTP)
  - Offers a bidirectional, full-duplex communication channel over a single, long-lived TCP connection
  - Browsers can upgrade from HTTP to websockets
- Suitable for real-time applications such as chat applications, online gaming, and financial trading platforms!

Why arose?

- HTTP 1.0: one-to-one mapping between HTTP request and some resource (html page, image etc)
- HTTP 1.1 introduced AJAX, clients request and receive data asynchronously (without a page refresh)
  - AJAX still requires client to initiate the requests

- Scenario: Live cricket score/commentary
  - Client visits site and sees “latest” content, but content out of date soon after page loads
  - AJAX can be used for “client polling” i.e. regularly sends requests to server
  - May work in some, but not in all scenarios
    - When data does not change often, can generate high volume of requests with no useful data returned!
- Web Sockets can help in this scenario!

Web Socket Implementation

Step1:

- WebSocket connections are normally created using client-side JavaScript
  a. var ws = new WebSocket("wss://example.com/chat");
- Results in HTTP request by client to server to establish the websocket connection

```
GET /chat HTTP/1.1
Host: example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Key: eahmIJKXbCLsvSIum89jqZN=
Sec-WebSocket-Version: 13
Cookie: session=MPc5LQosLb11g9BDKaMexoAG9tDaabL4
```

- Request includes an **Upgrade** header which indicates that the client wants to switch to the webSocket protocol
- **Sec-WebSocket-Key** is a randomly generated value
  - Serves as a unique identifier for the client
  - Part of challenge-response mechanism

Step2: Server Response to Upgrade

- If server supports WebSockets and request is ok, responds with HTTP 101 status code (Switching Protocols)
- Also includes a Connection header indicating WebSocket protocol upgrade
- Sec-WebSocket-Accept header contains a value derived from the Sec-WebSocket-Key
  - Server concatenates the value of Sec-WebSocket-Key with a predefined string and then hashes it using SHA-1

HTTP/1.1 101 Switching Protocols
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept:
q3MQLsoiQm1Q9kMIczhZGbK+yOo:

Step3:

- Once the WebSocket handshake is complete, connection is established
  - Both client and server can start sending messages back and forth

Step 4: Sending and Receiving Messages:

- Messages are typically sent as binary or text in **WebSocket frames**
- A simple message could be sent using JavaScript like ws.send("Hello");
- Common for JSON to be used to send structured data within WebSocket messages

- WebSocket frame: basic unit of communication
  - Encapsulates data being sent
  - Types of data:
    - text/binary data
    - control frames for managing connection and
    - continuation frames for large messages
  - Key components:
    - Header: Frame begins with a header that tells its length, type, and whether it is masked or not
      - Masking (Optional): payload data is XORed with a masking key to obfuscate contents
    - Payload: actual data being transmitted (binary or text)

Example

- A single-frame unmasked text message

0x81 0x05 0x48 0x65 0x6c 0x6c 0x6f
(contains "Hello")

- A single-frame masked text message

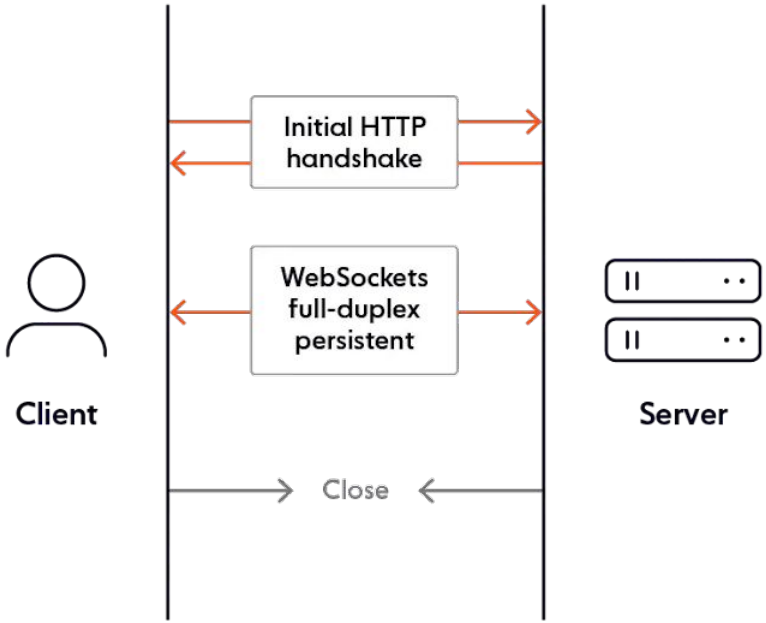
0x81 0x85 0x37 0xfa 0x21 0x3d 0x7f 0x9f 0x4d
0x51 0x58
(contains "Hello")

Step5: Closing WebSocket Connection

- Either the client or server can initiate the closure by sending a special close frame
- Upon receiving this frame, the other party also responds with a close frame
- And connection is closed and resources freed up!

In the cricket scenario example,

- Once initial page is loaded, no further communication occurs until server has an update
- Server pushes the update over websocket connection
- And cycle repeats


Initial HTTP handshake
WebSockets full-duplex persistent
Client
Server
Close

Websockets and SOP+CORS

- SOP: Restricts how requesting origin can interact with resources retrieved from another origin
- CORS: Extends SOP to allow access to cross-origin resources
- With web sockets, client-server communication occurs over the WS protocol (i.e., ws:// or wss://) → Not same origin, but cross-origin

- However, cross-origin data access restrictions imposed by SOP or for that matter CORS does not apply to WebSockets
  - SOP only pertains to HTTP response data
    - HTTP update response has no data
    - SOP cannot instruct the browser to restrict access to data transmitted via WebSockets.
  - WS do not support custom headers within WS handshake → CORS policy cannot be inserted into an HTTP Upgrade response

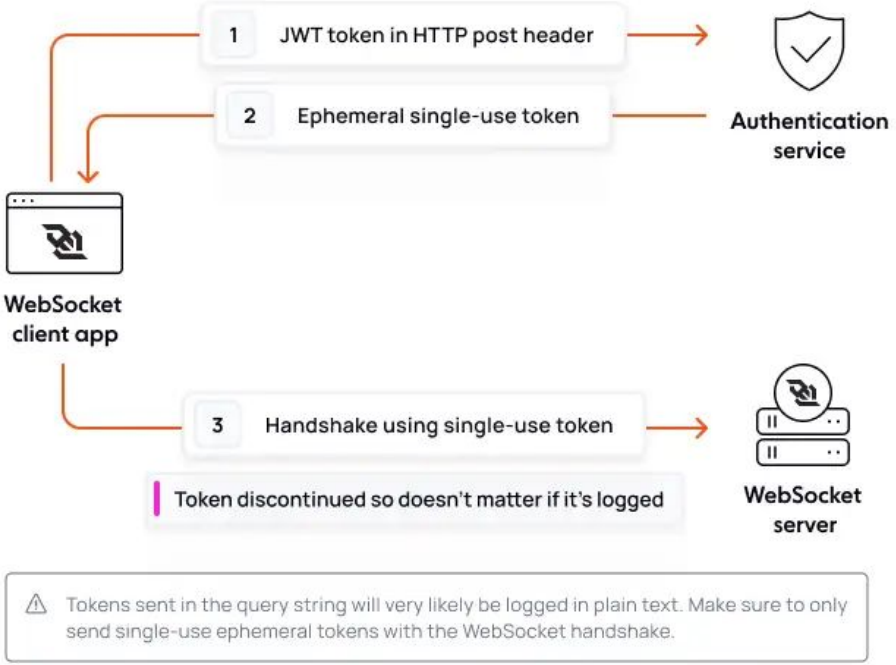
Authentication in Web Sockets

- Specification does not prescribe how to authenticate a WebSocket connection
  - Suggests authenticate the HTTP handshake before establishing the connection
- Often a token is used
  - A JSON Web Token (JWT) or
  - A session token obtained from a previous login process

Option-1: Access token in query parameter

- Pass credentials (access token) via URL
  - wss://example.com?token=your_token_here
- Very easy to implement
- If TLS is used, query strings are encrypted in transit
- WebSocket URLs aren’t really exposed to user
  - Users can't bookmark or copy-and-paste them → minimizes risk of accidental sharing
- However, URL with query parameters likely logged
  - If attacker can access logs, attacker can access data

Option-2: One-time token in query parameter



- By the time the token is logged on server, it will either have already been used or expired
- Better in security than option-1 but need to implement a custom and stateful authentication

Option-3: Authenticate over WebSocket Connection

- Send credentials in the first message post-connection over WebSocket
- Server must validate the token before allowing the client to do anything else!
  - If token invalid, server should terminate connection
- Need to define own custom authentication (session handling, timeouts etc)

Option-4: Using Cookie

- WebSocket handshake supports cookies → can authenticate the request
- However this will not work if WebSocket server is hosted on a different domain than web app
  - Browser will not send cookies due to SOP

```
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Cookie: session=MPc5LQosLb11g9BDKaMexoAG9tDaabL4
```

Vulnerabilities

- Any web security vulnerability that normally occurs can arise in WebSockets too!
  - User-supplied input can be processed in unsafe ways → SQL injection, XSS etc

XSS

- Consider a chat application based on WebSockets
- User types a message, following sent to Server
  - {"message":"Hello!"}
  - Rendered in user's browser as <td>Hello!</td>
- Assuming no defenses in place, attacker can send {"message":"<img src=1 onerror='alert(1)'>"}
  - Alert popped!

Cross Site Websocket Hijacking

- Also called cross-origin WebSocket hijacking
- Exploits cross-site request forgery (CSRF) vulnerability on a WebSocket handshake
  - Requires WebSocket handshake to rely solely on HTTP cookies
  - Session handling does not contain any CSRF tokens or other unpredictable values!

- User visits malicious website (A)
- A opens a websocket connection to victim website (B)
  - Browser will send user cookies to B and authenticates user (without knowledge of user)
- A can then send arbitrary messages to B and also read responses
  - Why? SOP does not apply to websockets
- Unlike regular CSRF, attacker gains two-way interaction with the compromised website (B)

Defense

- SOP and CORS don't apply to Websockets → WebSocket server should verify origin of HTTP Upgrade request
  - Reject connections from unexpected or unauthorized origins
  - Origin check should be done on top of authentication and authorization checks (Not a replacement)
- Use the wss:// protocol (WebSockets over TLS) as opposed to ws://

- Treat data received via the WebSocket as untrusted in both directions
  - Handle data safely to prevent input-based vulnerabilities such as SQL injection and XSS
- Use CSRF tokens as part of user's session to avoid attacks like Cross Site Websocket Hijacking
  - Attackers cannot forge requests if they cannot guess the token

Real Life Examples

Cross Site WebSocket Hijacking:
https://hackerone.com/reports/535436

References

- https://portswigger.net/web-security/websockets
- https://ably.com/topic/websocket-security and https://ably.com/blog/websocket-authentication
- WebSocket Protocol: https://datatracker.ietf.org/doc/html/rfc6455

Summary

- Offer a bi-directional, full duplex communication channel over TCP
- Implemented via HTTP Upgrade, websocket frames
  - SOPS or CORS do not apply to them
- Authentication is challenging, but options exist
- Vulnerable to usual web vulnerabilities
  - Cross Site Websocket Hijacking is a new attack!
- Defense: check origin, use of wss, CSRF tokens