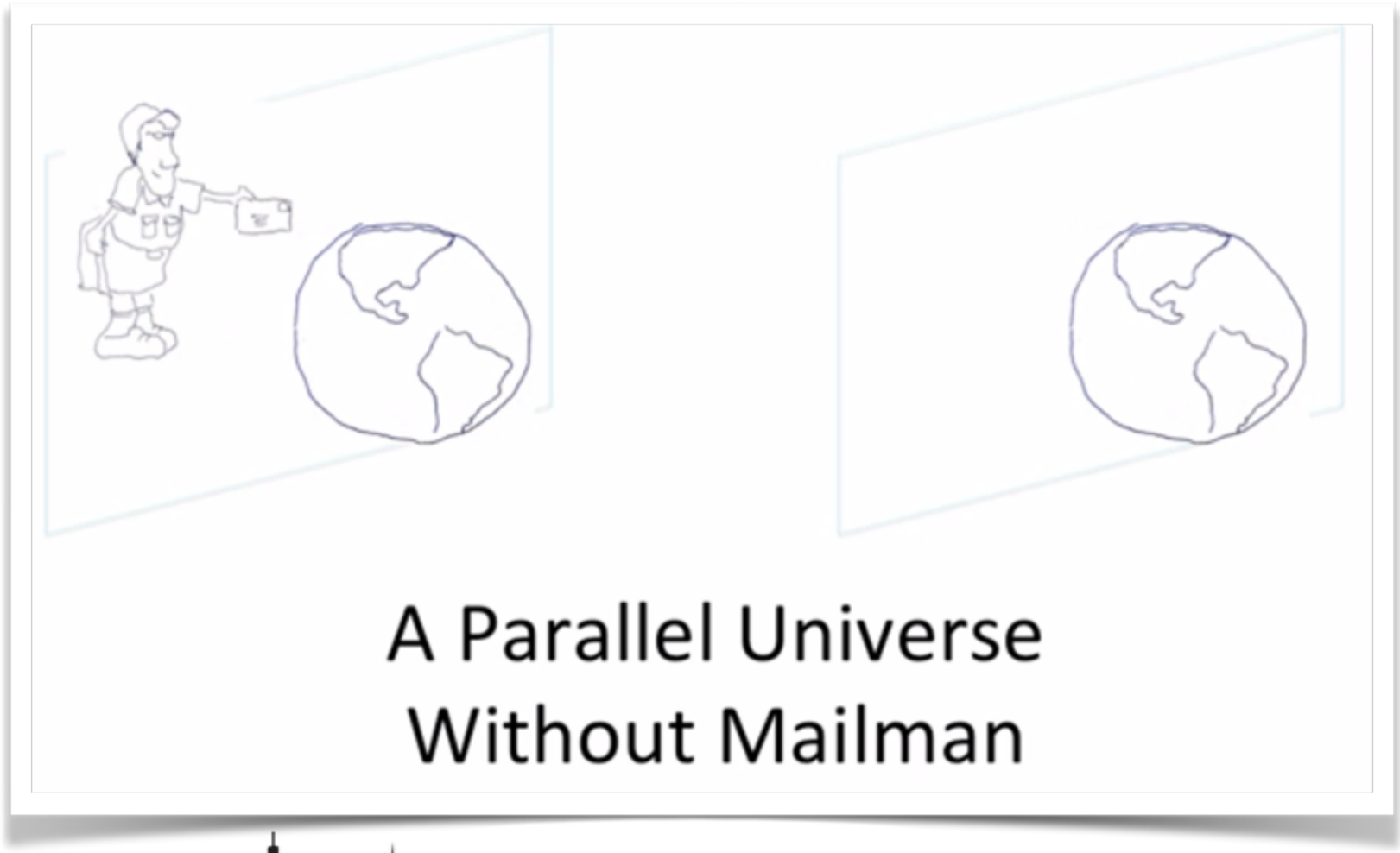
Nuts and Bolts of WebSocket

Arun Gupta, Red Hat

Agenda

- Introduction
- WebSocket and Node.js
- WebSocket using JSR 356
  - Server
  - Client
- Securing WebSocket
- Embedded WebSocket
- Load Balance WebSocket
- Pub/Sub over WebSocket
  - STOMP over WebSocket
  - MQTT over WebSocket
- REST and SSE
- Scalability
- Debugging
- Production Tips

The “long” story of WebSocket



“Limitations” of HTTP

- Client-driven
- Half-duplex
- Verbose
- New TCP connection

“Hello World” HTTP

```
POST /websocket-vs-rest-payload/webresources/rest HTTP/1.1\r\n
Host: localhost:8080\r\n
Connection: keep-alive\r\n
Content-Length: 11\r\n
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_9_1) AppleWebKit/537.36 (KHTML, like Gecko) Chrome/32.0.1700.107 Safari/537.36\r\n
Origin: chrome-extension://hgmloofddffdnphfgcellkdfbfbjeloo\r\n
Content-Type: text/plain \r\n
Accept: */*\r\n
Accept-Encoding: gzip,deflate,sdch\r\n
Accept-Language: en-US,en;q=0.8\r\n
\r\n
```

663 bytes

```
HTTP/1.1 200 OK\r\n
Connection: keep-alive\r\n
X-Powered-By: Undertow 1\r\n
Server: Wildfly 8 \r\n
Content-Type: text/plain\r\n
Content-Length: 11 \r\n
Date: Fri, 21 Feb 2014 21:27:53 GMT \r\n
\r\n
```

How WebSocket solves it ?

- Bi-directional (client-driven)
- Full-duplex (half-duplex)
- Lean protocol (verbose)
- Single TCP connection (new TCP)

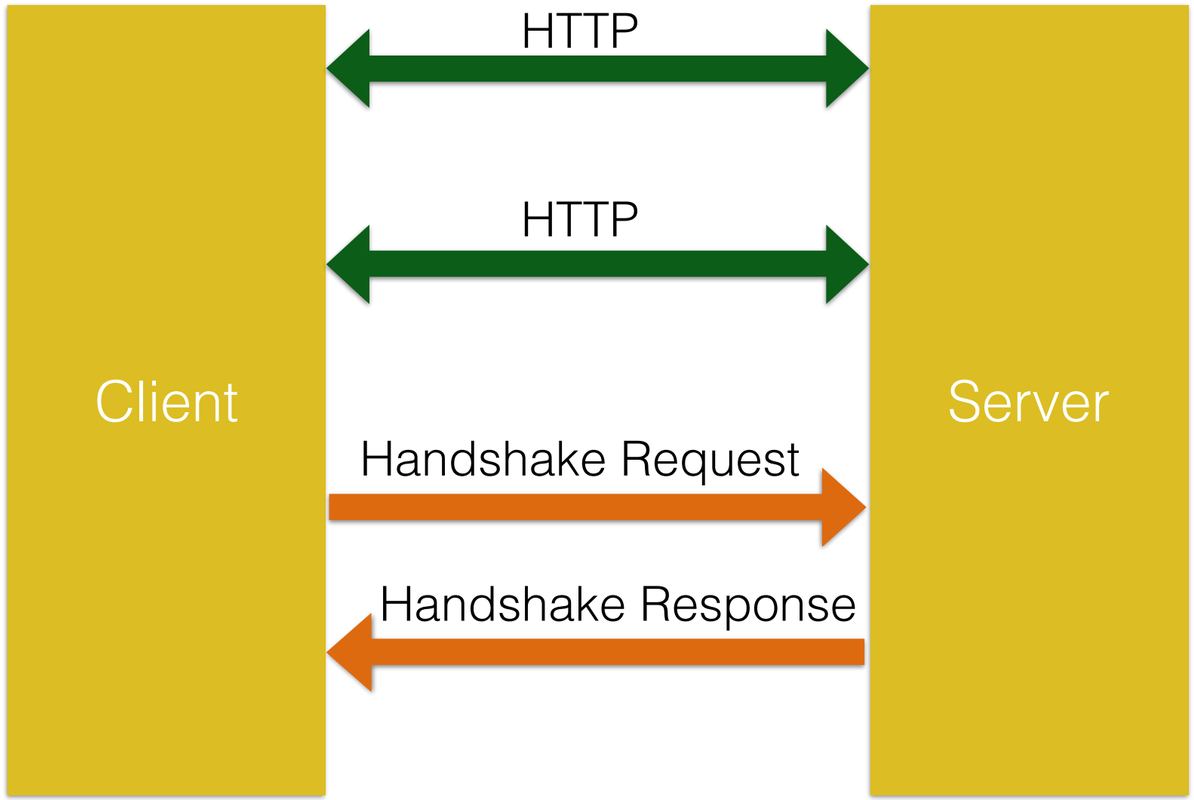
What is WebSocket ?

- Bi-directional, full-duplex, communication channel over a single TCP connection
- Originally proposed as part of HTML5
- IETF-defined **Protocol**: RFC 6455
- W3C-defined **JavaScript API**

How does it work ?

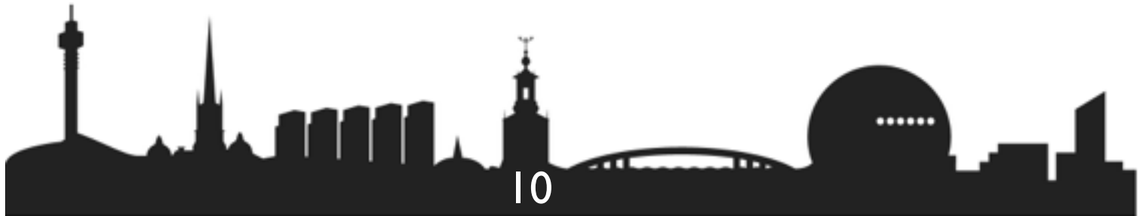
- Upgrade HTTP to WebSocket (single TCP connection)
- Send data frames in both direction (bi-directional)
- Send messages independent of each other (full-duplex)
- End the connection

How does it work ?



Handshake Request

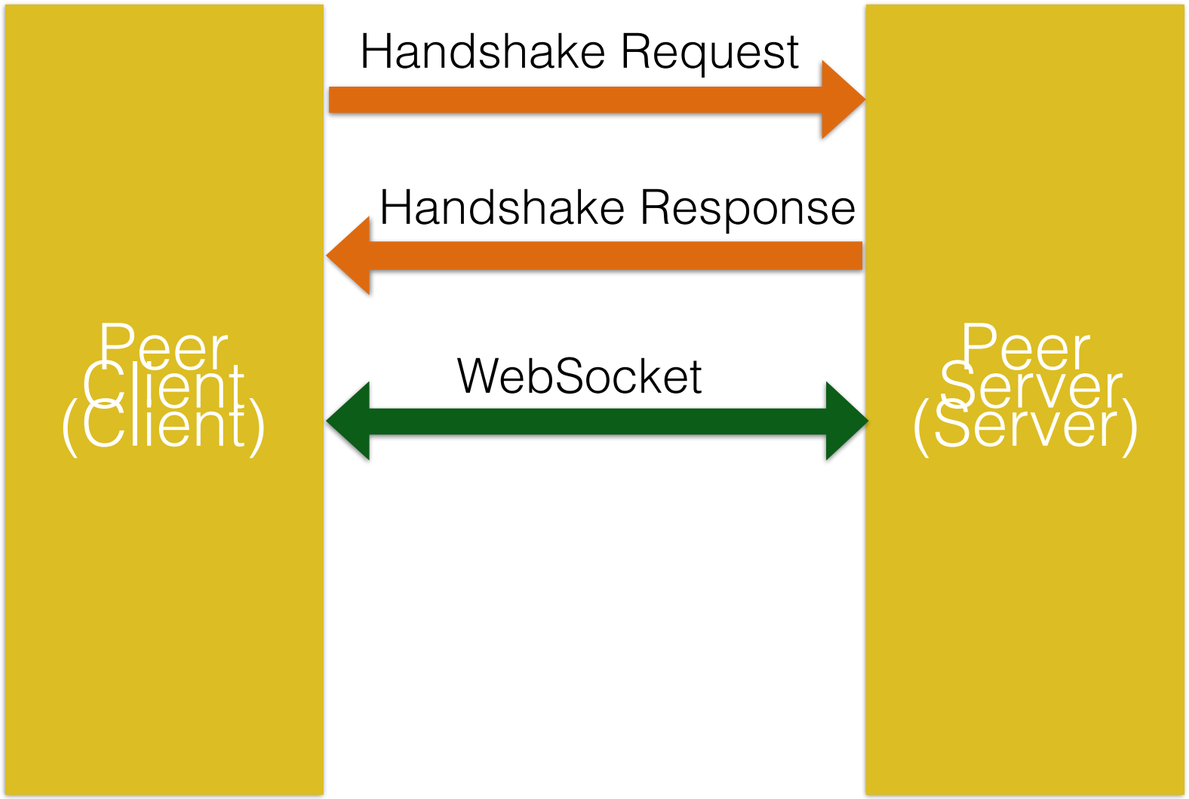
```
GET /chat HTTP/1.1
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Origin: http://example.com
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
Sec-WebSocket-Protocol: chat, superchat
Sec-WebSocket-Version: 13
```

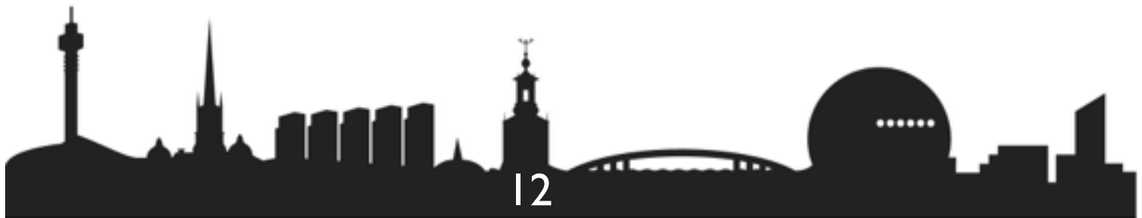


Handshake Response

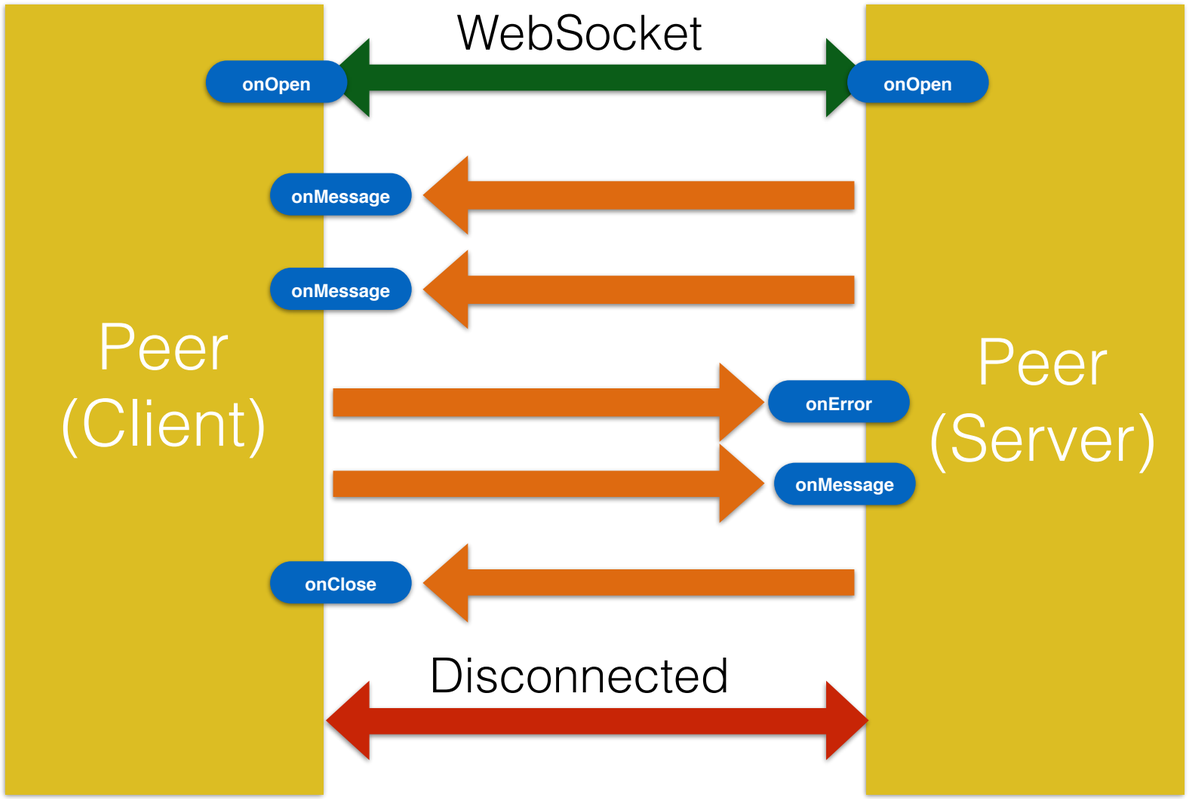
```
HTTP/1.1 101 Switching Protocols
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
Sec-WebSocket-Protocol: chat
```

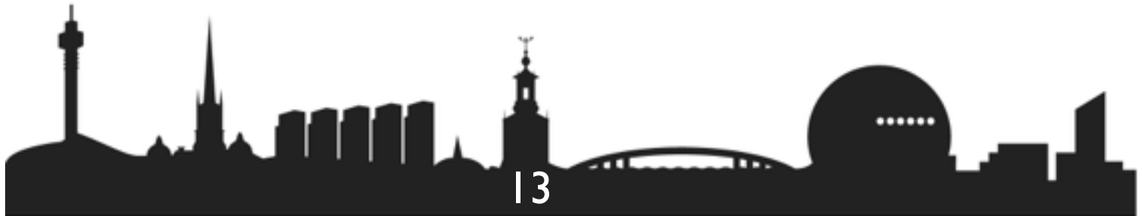
How does it work ?





How does it work ?





WebSocket Subprotocols

- Facilitates application layer protocols
- Registered in a Subprotocol name registry
  - Identifier, common name, definition
  - www.iana.org/assignments/websocket/websocket.xml#subprotocol-name
    - STOMP, XMPP, MQTT, SOAP, …

WebSocket Extensions

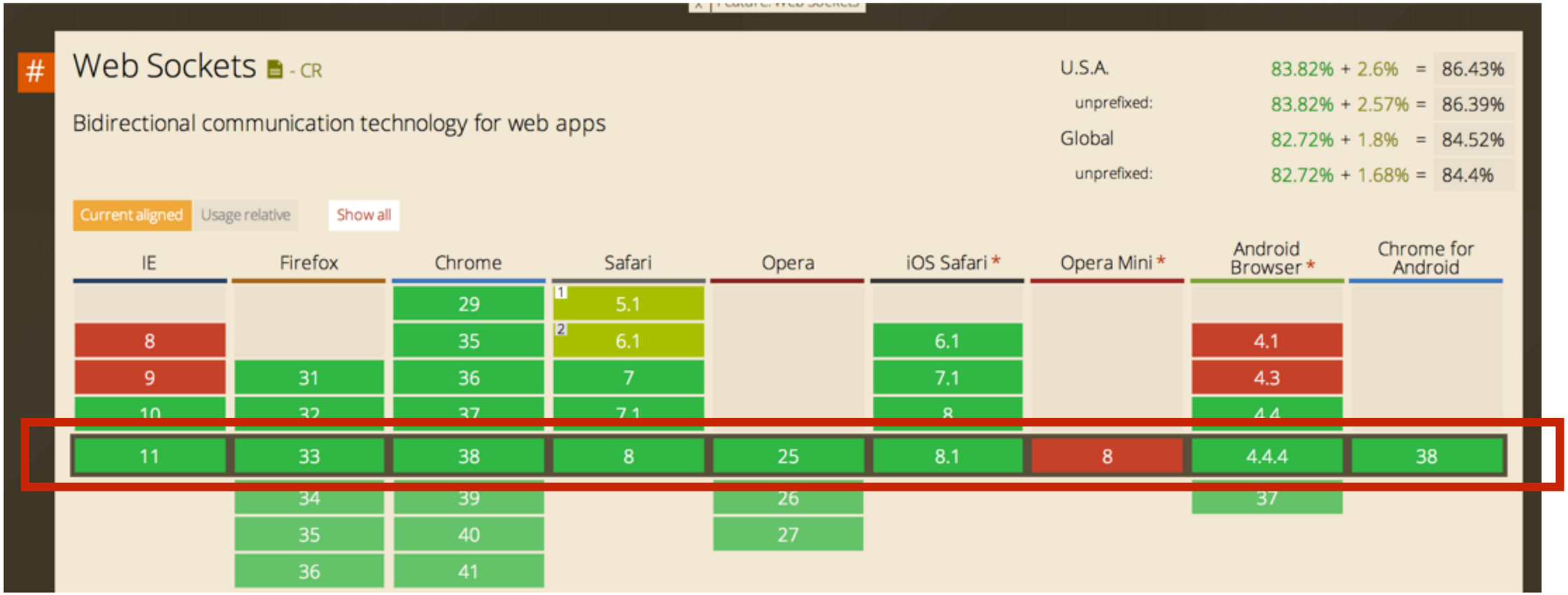
- Add capabilities to the base protocol
- Multiplexing
  http://tools.ietf.org/html/draft-tamplin-hybi-google-mux
- Compression: Only non-control frames/messages
  - Per-frame
    http://tools.ietf.org/html/draft-tyoshino-hybi-websocket-perframe-deflate
  - Per-message
    http://tools.ietf.org/html/draft-ietf-hybi-permessage-compression

WebSocket JavaScript API

```
[Constructor(DOMString url, optional (DOMString or DOMString[]) protocols)]
interface WebSocket : EventTarget {
  readonly attribute DOMString url;

  // ready state
  const unsigned short CONNECTING = 0;
  const unsigned short OPEN = 1;
  const unsigned short CLOSING = 2;
  const unsigned short CLOSED = 3;
  readonly attribute unsigned short readyState;
  readonly attribute unsigned long bufferedAmount;

  // networking
           attribute EventHandler onopen;
           attribute EventHandler onerror;
           attribute EventHandler onclose;
  readonly attribute DOMString extensions;
  readonly attribute DOMString protocol;
  void close([Clamp] optional unsigned short code, optional DOMString reason);

  // messaging
           attribute EventHandler onmessage;
           attribute DOMString binaryType;
  void send(DOMString data);
  void send(Blob data);
  void send(ArrayBuffer data);
  void send(ArrayBufferView data);
};
```

www.w3.org/TR/websockets

Support in Browsers



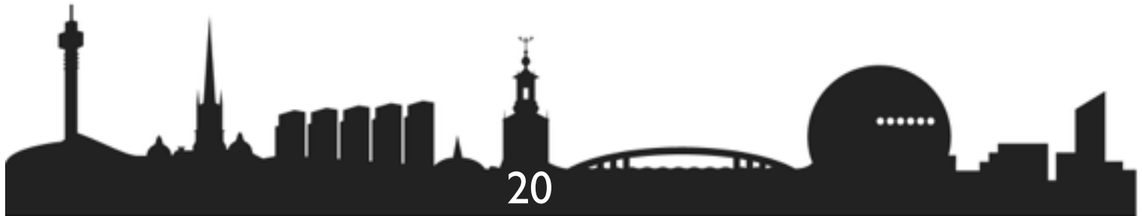
caniuse.com/websockets

Developer Tools


OPENSHIFT

Java API for WebSocket

- API for WebSocket server and client endpoint
  - Annotated: `@ServerEndpoint, @ClientEndpoint`
  - Programmatic: `Endpoint`
    - WebSocket opening handshake negotiation
- Lifecycle Callback methods
- Integration with Java EE technologies



Annotated Endpoint

```
import javax.websocket.*;

@ServerEndpoint("/hello")
public class HelloBean {
  @OnMessage
  public String sayHello(String name) {
    return "Hello " + name;
}
```

WebSocket Annotations

- Class-level annotations
  - `@ServerEndpoint`: Turns a POJO in a server endpoint
  - `@ClientEndpoint`: Turns a POJO in a client endpoint

WebSocket Annotations

- Method-level annotations
  - `@OnMessage`: Intercepts WebSocket messages
  - `@OnOpen`: Intercepts WebSocket open events
  - `@OnClose`: Intercepts WebSocket close events
  - `@OnError`: Intercepts WebSocket error events

WebSocket Annotations

- Parameter-level annotations
  - `@PathParam`: Matches path segment of a URI-template

@ServerEndpoint attributes

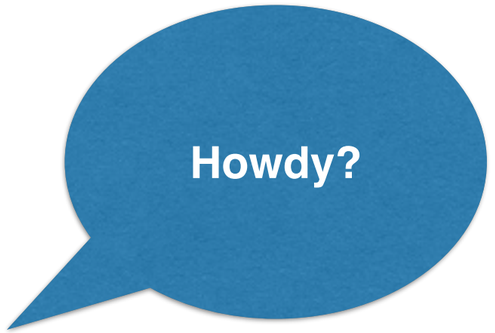
- `value`: Relative URI or URI template e.g. '/hello' or '/chat/{subscriber-level}'
- `decoders`: list of message decoder classnames
- `encoders`: list of message encoder classnames
- `subprotocols`: list of the names of the supported subprotocols

Chat Server

```
@ServerEndpoint("/chat")
public class ChatBean {
  static Set<Session> peers = Collections.synchronizedSet("...");

  @OnOpen
  public void onOpen(Session peer) {
    peers.add(peer);
  }

  @OnClose
  public void onClose(Session peer) {
    peers.remove(peer);
  }

  @OnMessage
  public void message(String message) {
    for (Session peer : peers) {
      peer.getBasicRemote().sendObject(message);
    }
  }
}
```

Chat Server Simplified

```
@ServerEndpoint("/chat")
public class ChatBean {
  @OnMessage
  public void message(String message, Session endpoint) {
    for (Session peer : endpoint.getOpenSessions()) {
      peer.getBasicRemote().sendObject(message);
    }
  }
}
```



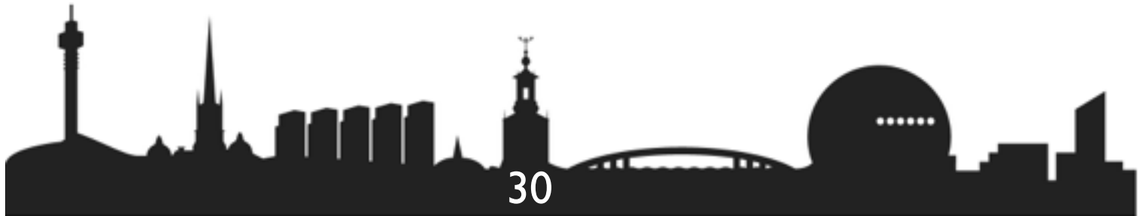
https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/chat

Custom Payloads

```
@ServerEndpoint(
  value="/hello",
  decoders={MyMessageDecoder.class},
  encoders={MyMessageEncoder.class}
)
public class MyEndpoint {
  . . .
}
```

Custom Payloads: Text decoder

```
public class MyMessageDecoder implements Decoder.Text<MyMessage> {
  public MyMessage decode(String s) {
    JsonObject jsonObject = Json.createReader("...").readObject();
    return new MyMessage(jsonObject);
  }

  public boolean willDecode(String string) {
    . . .
    return true;
  }

  . . .
}
```



Custom Payloads: Text encoder

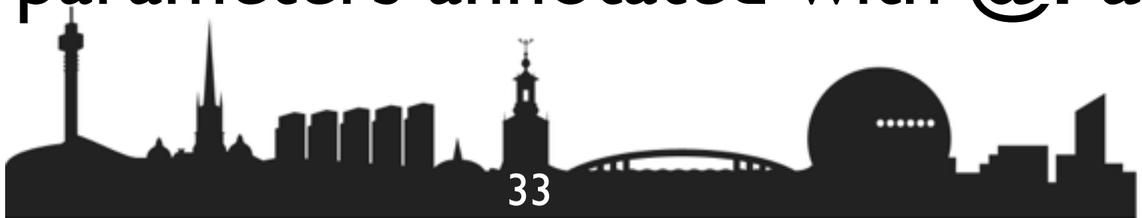
```
public class MyMessageDecoder implements Encoder.Text<MyMessage> {
  public String encode(MyMessage myMessage) {
    return myMessage.jsonObject.toString();
  }

  . . .
}
```

Custom Payloads: Binary decoder

```
public class MyMessageDecoder implements Decoder.Binary<MyMessage> {
  public MyMessage decode(byte[] s) {
    . . .
    return myMessage;
  }

  public boolean willDecode(byte[] string) {
    . . .
    return true;
  }

  . . .
}
```

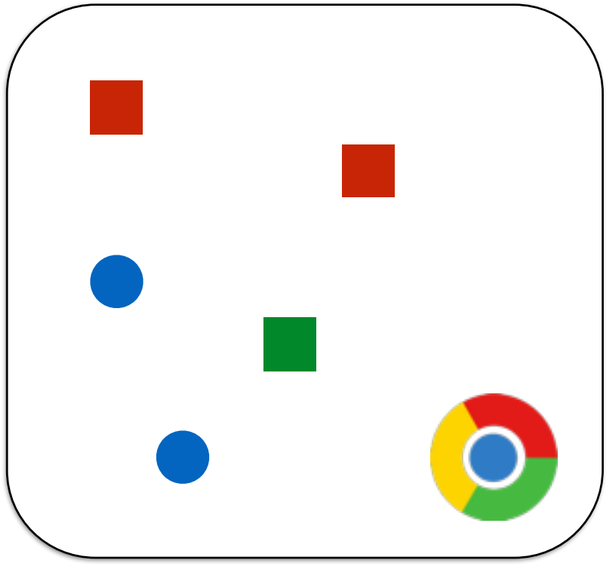
Method Signatures

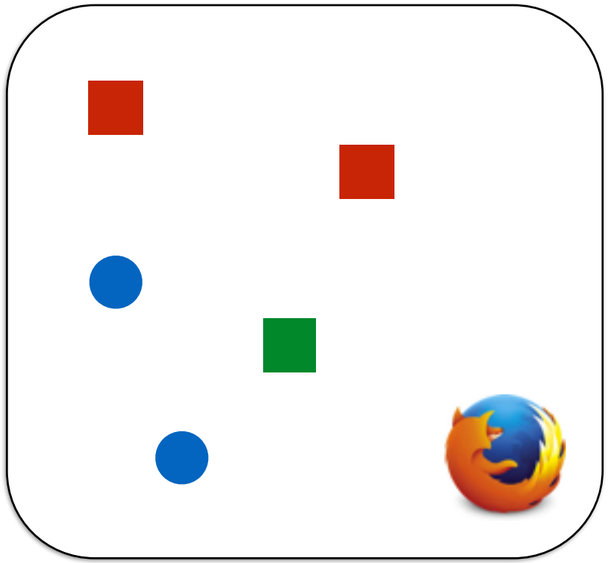
- Exactly one of the following
  - **Text**: `String`, `boolean`, Java primitive or equivalent class, `Reader`, any type for which there is a decoder
  - **Binary**: `byte[]`, `ByteBuffer`, `byte[]` and `boolean`, `ByteBuffer` and `boolean`, `InputStream`, any type for which there is a decoder
  - **Pong** messages: `PongMessage`
- An optional **Session** parameter
- 0..n String parameters annotated with **@PathParam**



Sample Messages

- `void m(String s);`
- `void m(Float f, @PathParam(“id”)int id);`
- `Product m(Reader reader, Session s);`
- `void m(byte[] b); or void m(ByteBuffer b);`
- `Book m(int i, Session s, @PathParam(“isbn”)String isbn, @PathParam(“store”)String store);`





https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/whiteboard

URI Template Matching

```
@ServerEndpoint("/chat/{roomid}")
public class ChatServer {
  @OnMessage
  public void receiveMessage(
    @PathParam("roomid")String roomId) {
    . . .
  }
}
```

Client Endpoint

```
@ClientEndpoint
public class HelloClient {
  @OnMessage public void message(
    String message,
    Session session) {
    //. . .
  }
}
```

```
WebSocketContainer c = ContainerProvider.getWebSocketContainer();
c.connectToServer(HelloClient.class, "hello");
```

lorem ipsum dolor

lorem ipsum dolor

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/google-docs

Programmatic Endpoint

```
public class ChatServer extends Endpoint {
  @Override
  public void onOpen(Session session) {
    session.addMessageHandler(new MessageHandler.Text() {
      public void onMessage(String message) {
        try {
          session
           .getBasicRemote()
           .sendText(message);
        } catch (IOException ex) { }
      }
    });
  }
}
```

Programmatic Endpoint Config

```
public class MyEndpointConfig implements ServerApplicationConfig {

    @Override
    public Set<ServerEndpointConfig> getEndpointConfigs(
        Set<Class<? extends Endpoint>> set) {
        return new HashSet<ServerEndpointConfig>() {
            {
                add(ServerEndpointConfig.Builder
                    .create(ChatServer.class, "/chat")
                    .build());
            }
        };
    }

    @Override
    public Set<Class<?>> getAnnotatedEndpointClasses(Set<Class<?>> set) {
        return Collections.emptySet();
    }
}
```

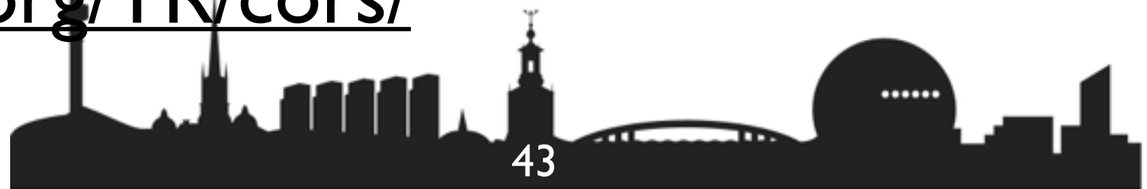
https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/endpoint-singleton

Securing WebSockets

- Origin-based security model
- Sec-xxx keys can not be set using XMLHttpRequest
  - Sec-WebSocket-Key, Sec-WebSocket-Version
- User-based security using Servlet security mechanism
  - Endpoint mapped by **ws://** is protected using security model defined using the corresponding http:// URI
  - Authorization defined using `<security-constraint>`
- Transport Confidentiality using **wss://**
  - Access allowed over encrypted connection only

Cross-Origin Resource Sharing

- Relaxes same-origin restrictions to network requests
- Servers include `Access-Control-Allow-Origin` HTTP header
- Access-Control-* headers
  - Max-Age
  - Allow-Methods
  - Allow-Headers
  - …
- www.w3.org/TR/cors/



User-based Security

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/endpoint-security

TLS-based Security

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/endpoint-wss

Embedded WebSocket

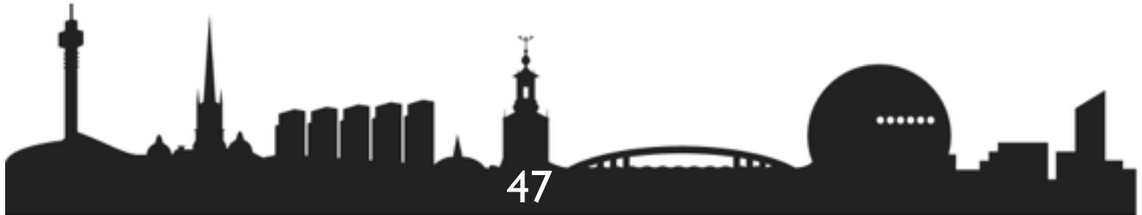
- **Undertow** New web server in WildFly 8
- Blocking and non-blocking based on NIO
- Composition/handler-based architecture
- Lightweight and fully embeddable
- Supports Servlet 3.1 and HTTP Upgrade
- mod_cluster supported

Undertow is awesome!

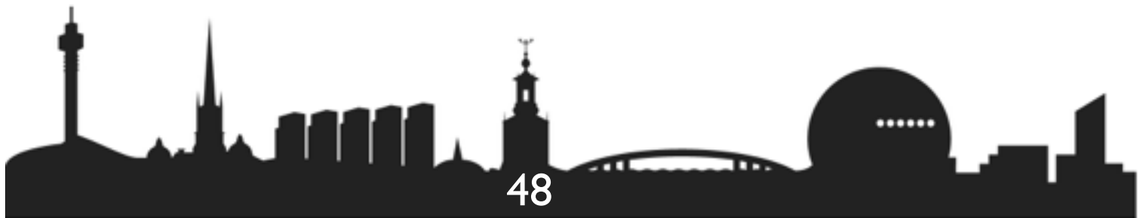
```
techempower@lg01:~$ wrk -d 30 -c 256 -t 40 http://10.0.3.2:8080/byte
Running 30s test @ http://10.0.3.2:8080/byte
  40 threads and 256 connections
  Thread Stats   Avg      Stdev     Max   +/- Stdev
    Latency   247.05us    3.52ms 624.37ms   99.90%
    Req/Sec    27.89k     6.24k   50.22k    71.15%
  31173283 requests in 29.99s, 3.83GB read
  Socket errors: connect 0, read 0, write 0, timeout 9
Requests/sec: 1039305.27
Transfer/sec:    130.83MB
```

This is output from Wrk testing a single server running Undertow using conditions similar to Google's test (1-byte response body, no HTTP pipelining, no special request headers) **1.039 million requests per second**.

http://www.techempower.com/blog/2014/03/04/one-million-http-rps-without-load-balancing-is-easy/



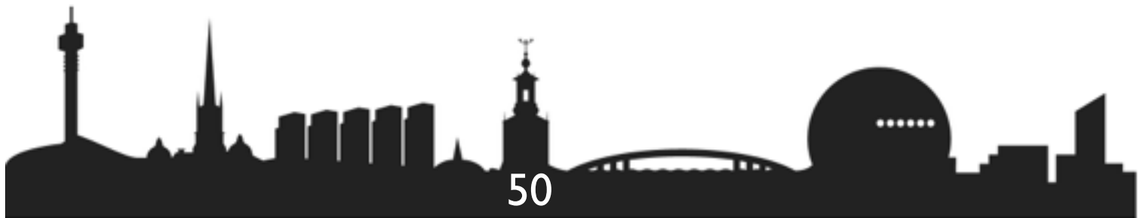
git@github.com:undertow-io/undertow.git



Load Balance WebSocket

- Reverse proxy
  - Apache module: `mod_proxy_wstunnel`
- Only vertical scaling
- No session replication

http://blog.arungupta.me/2014/08/load-balance-websockets-apache-httpd-techtip48/



STOMP over WebSocket

Stomp

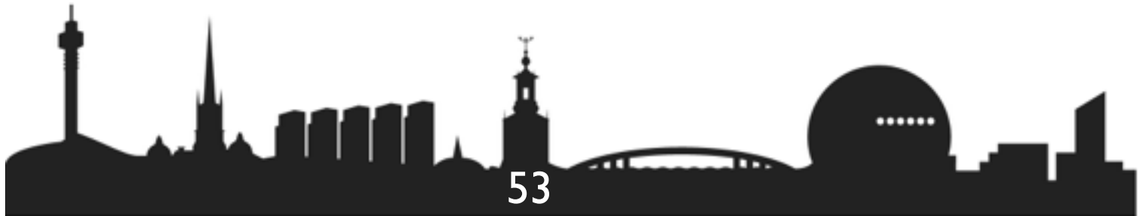
- STOMP: **S**imple **T**ext **O**riented **M**essaging **P**rotocol
- Interoperable wire format: any client, any broker
- Messaging interoperability among languages and platforms
  - Unlike JMS
- REST for messaging: CONNECT, SEND, SUBSCRIBE, . . .
- Map STOMP frames to WebSocket frames

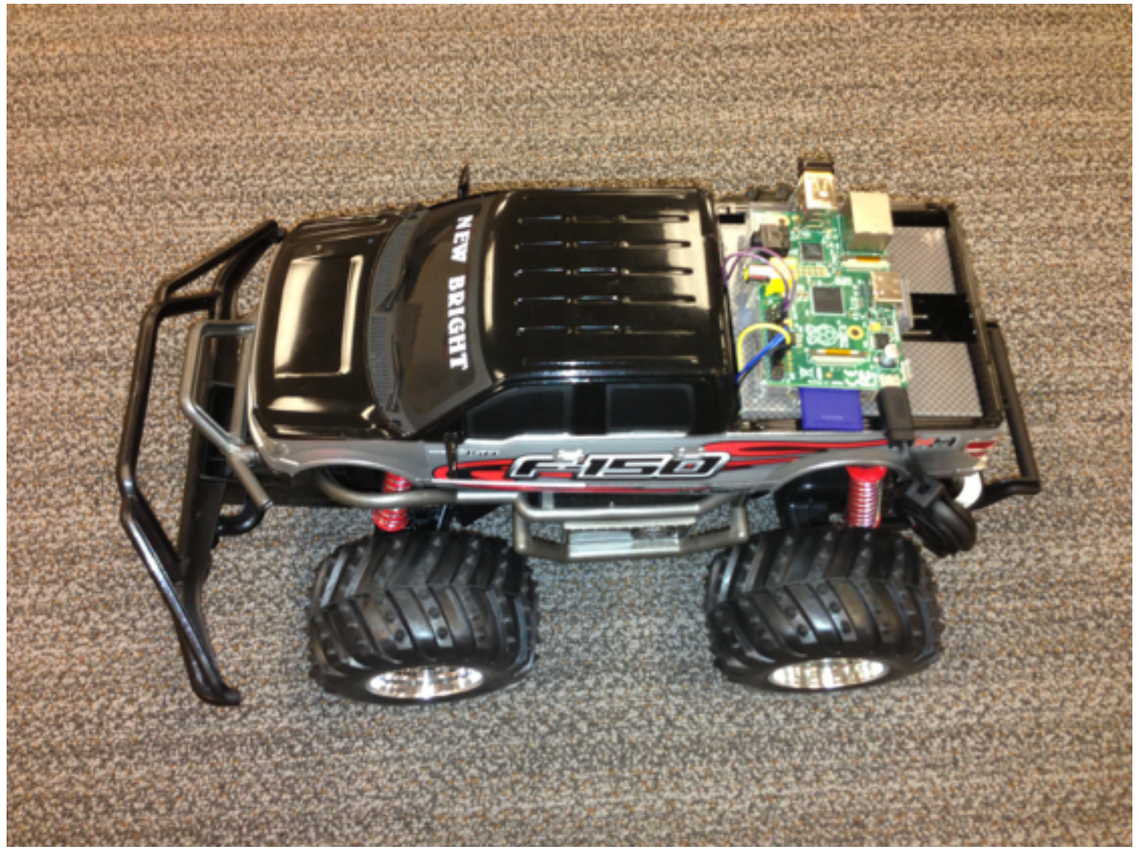
https://github.com/arun-gupta/wildfly-samples/tree/master/websocket-stomp

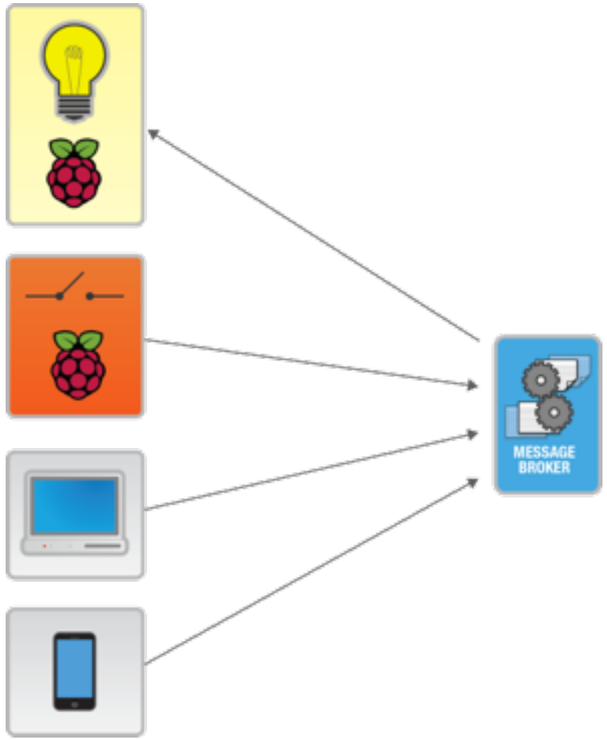
MQTT over WebSocket

Stomp

- Light-weight pub/sub messaging over TCP
- Designed for "small foot print" or limited bandwidth
- MQTT 3.1.1 is now an OASIS standard
- Plain byte array message payload
- Quality-of-Service: 0 (TCP), 1 (at least once), 2 (missed messages)
- "Last will and testament" publish a message after client goes offline







http://blog.kaazing.com/2013/10/01/controlling-physical-devices-on-the-real-time-web-kaazing-iot-talk-at-javaone-2013/

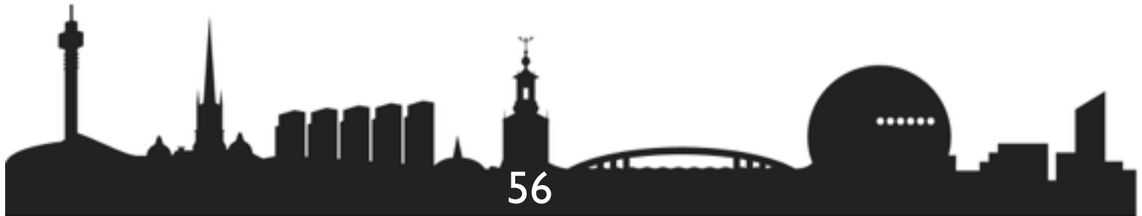
Compare with REST

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/websocket-vs-rest-payload

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/websocket-vs-rest

Server-Sent Events

- Part of HTML5 Specification
- Server-push notifications
- Cross-browser JavaScript API: `EventSource`
- Message callbacks
- MIME type: `text/eventstream`

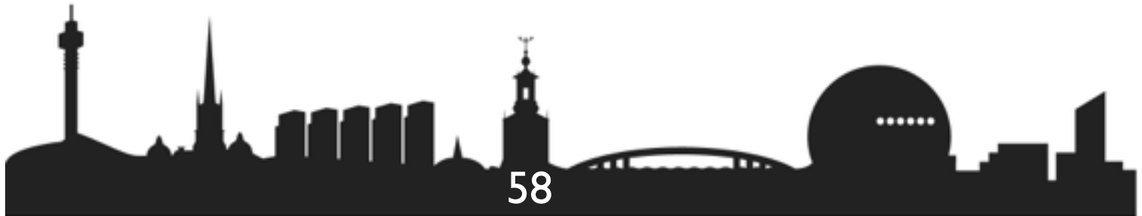


EventSource API

```
[Constructor(DOMString url, optional EventSourceInit eventSourceInitDict)]
interface EventSource : EventTarget {
  readonly attribute DOMString url;
  readonly attribute boolean withCredentials;

  // ready state
  const unsigned short CONNECTING = 0;
  const unsigned short OPEN = 1;
  const unsigned short CLOSED = 2;
  readonly attribute unsigned short readyState;

  // networking
  [TreatNonCallableAsNull] attribute Function? onopen;
  [TreatNonCallableAsNull] attribute Function? onmessage;
  [TreatNonCallableAsNull] attribute Function? onerror;
  void close();
};

dictionary EventSourceInit {
  boolean withCredentials = false;
};
```

WebSockets and SSE ?

WebSocket	Server-Sent Event
Over a custom protocol	Over simple HTTP
Full-duplex, bi-directional	Server-push only, client-server OOB
Native support in most browsers	Can be poly-filled to backport
Not straight forward protocol	Simpler protocol



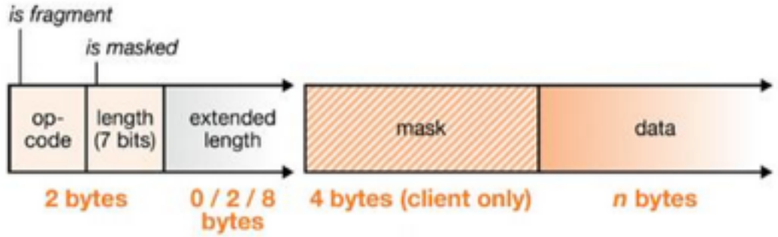
WebSockets and SSE ?

WebSocket	Server-Sent Event
Application-specific reconnection	Built-in support for reconnection and event id
Require server and/or proxy configurations	No server or proxy change required
Text and Binary	Text only
Pre-defined message handlers	Pre-defined and arbitrary

What makes them scalable ?

- No HTTP/TCP opening/closing connections
  - Handshake over a single TCP connection
  - HTTP connections have short connection timeout (5 secs for Apache)
- Elimination of HTTP headers (cookies, content-type, user-agent, …)
  - Reduces bandwidth dramatically

What makes them scalable ?

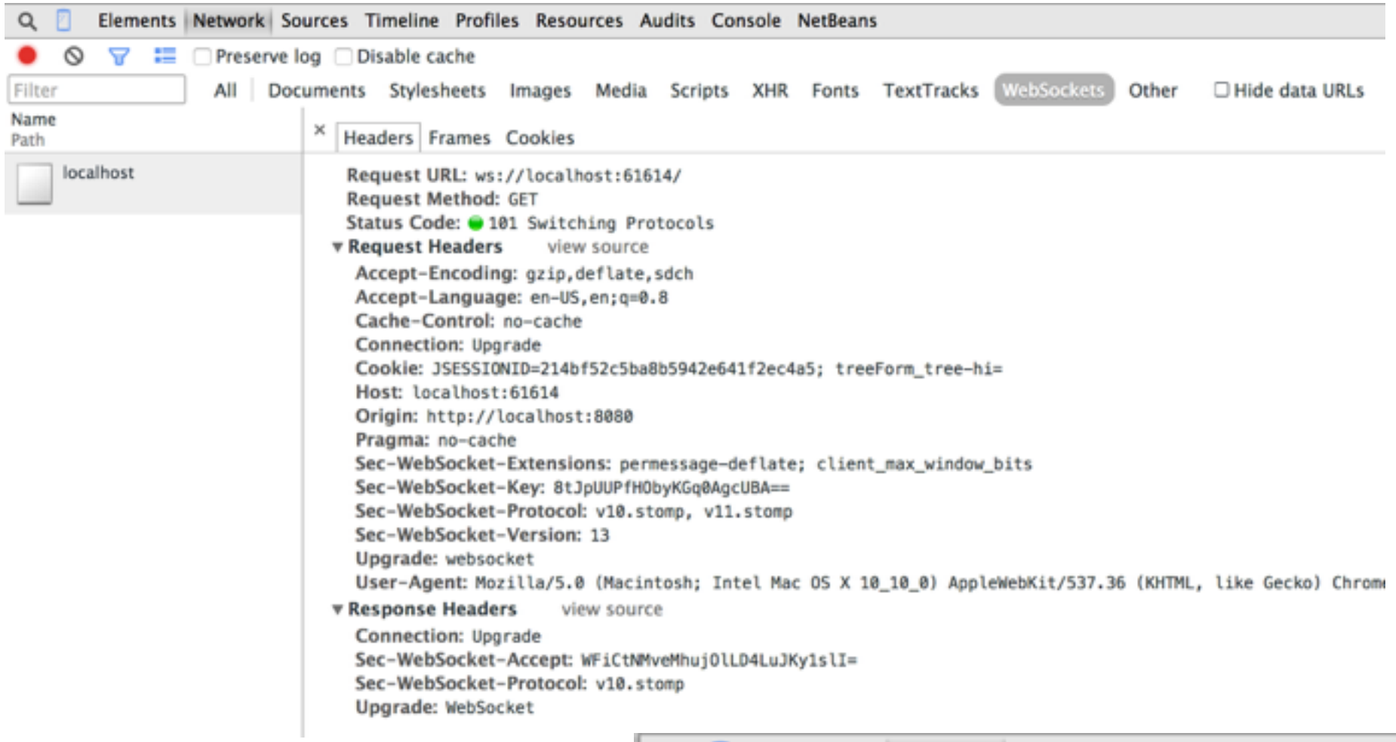


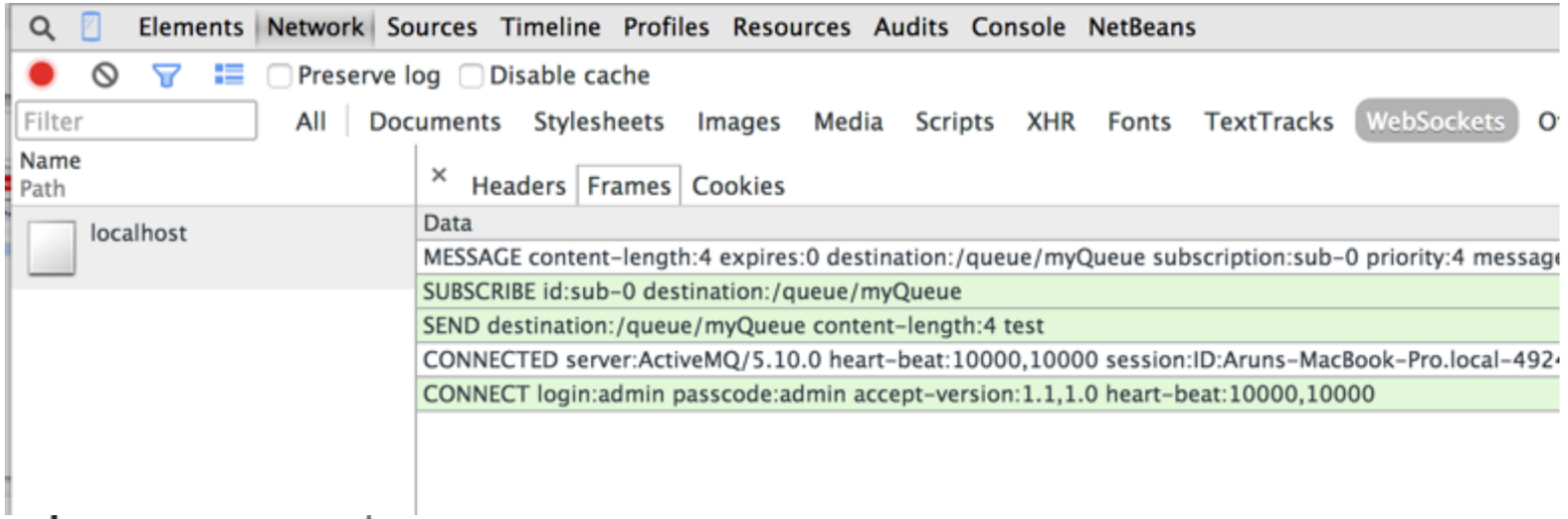
- Minimal data framing
  - 2-14 bytes overhead after handshake
- Maintaining a TCP connection on server is relatively inexpensive
- Smaller data fragments can be sent without out a request/ response
  - Live pushes, e.g. stock sticker
  - Lower latency

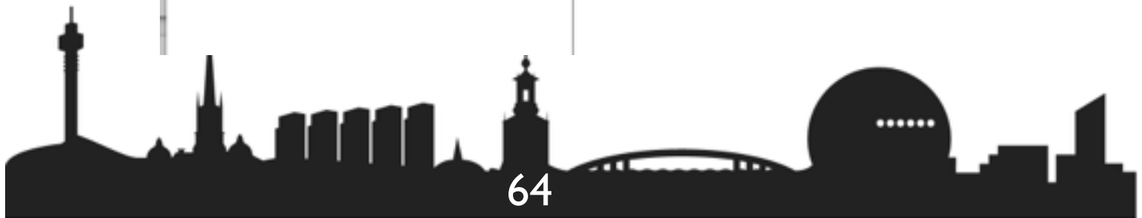
What makes them scalable ?

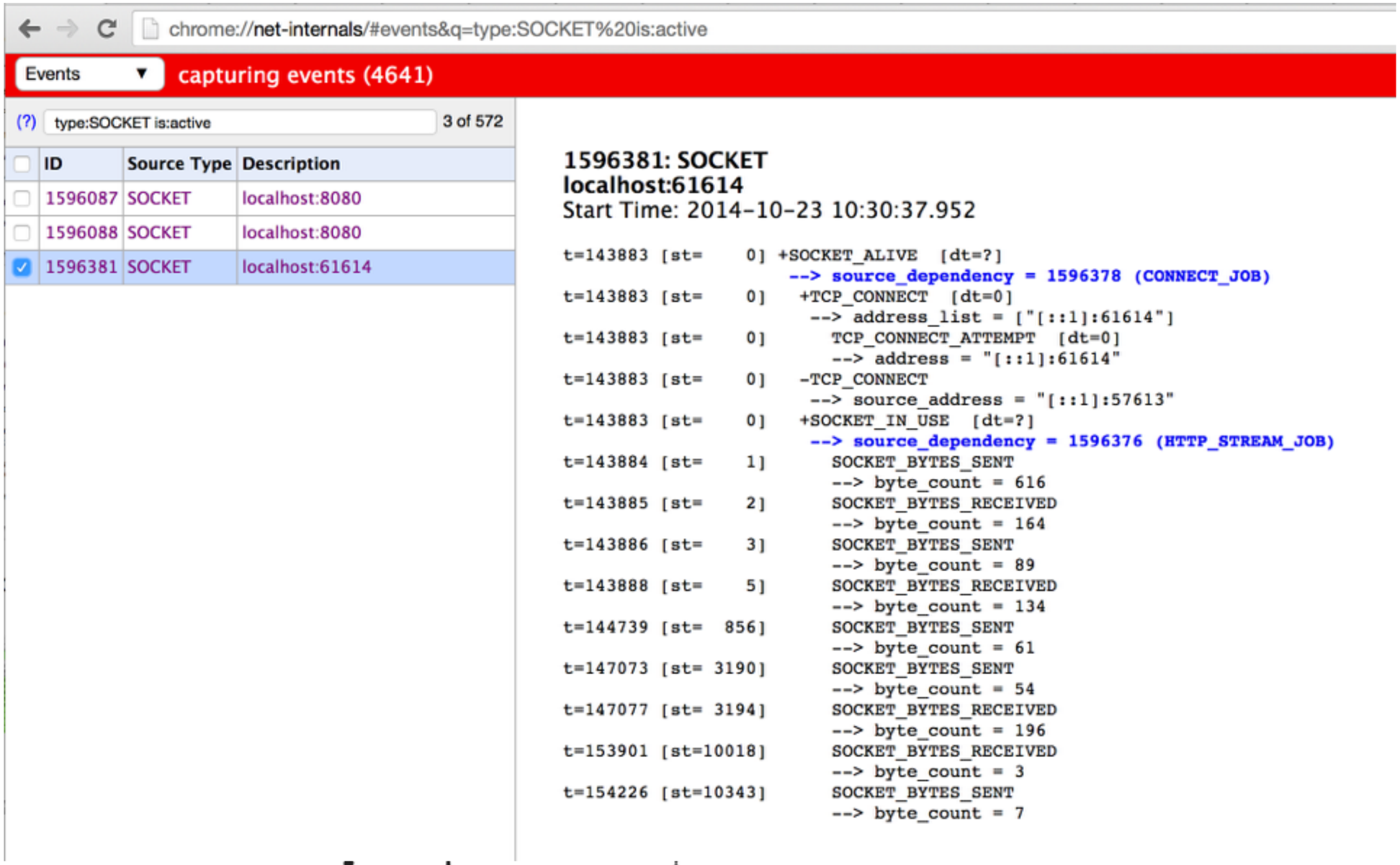
- WebSockets are good at scaling vertically
- HTTP servers are typically configured to log start/completion of HTTP request, not so for WebSocket
- Polling and Long-polling is a waste of bandwidth, WebSockets are more elegant
- Number of concurrent clients depend upon FD settings

Debugging WebSockets

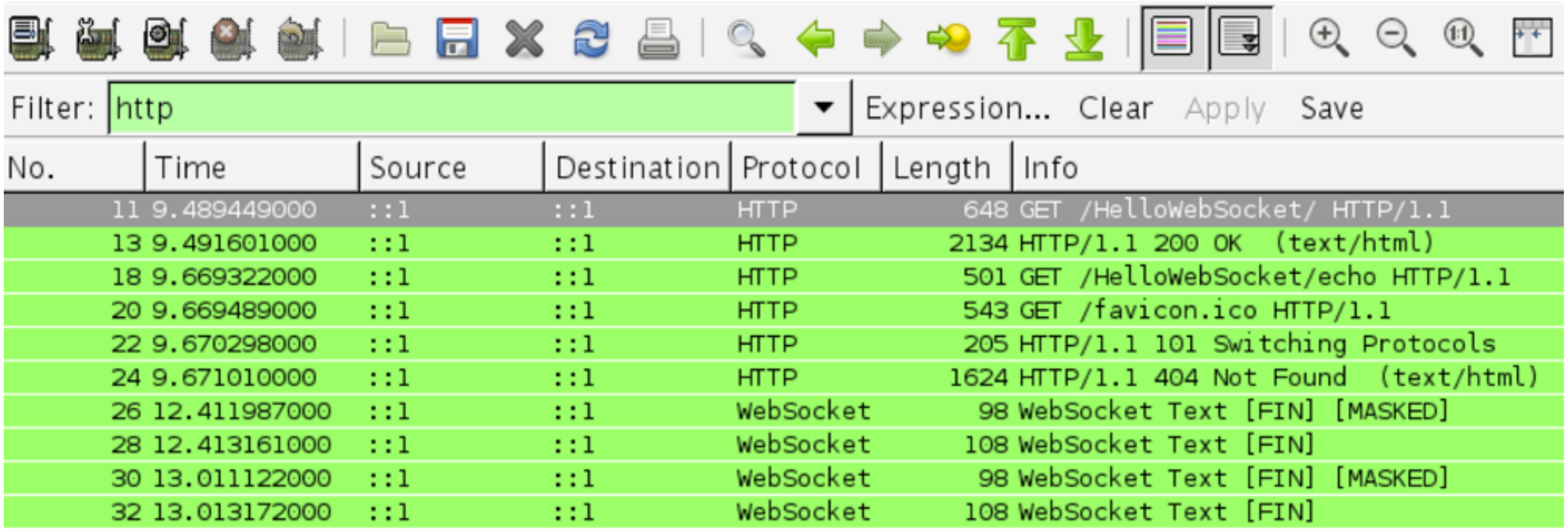

Elements Network Sources Timeline Profiles Resources Audits Console NetBeans
Preserve log Disable cache
Filter All Documents Stylesheets Images Media Scripts XHR Fonts TextTracks WebSockets Other Hide data URLs
Name
Path
localhost
Headers Frames Cookies
Request URL: ws://localhost:61614/
Request Method: GET
Status Code: 101 Switching Protocols
Request Headers view source
Accept-Encoding: gzip,deflate,sdch
Accept-Language: en-US,en;q=0.8
Cache-Control: no-cache
Connection: Upgrade
Cookie: JSESSIONID=214bf52c5ba8b5942e641f2ec4a5; treeForm_tree-hi=
Host: localhost:61614
Origin: http://localhost:8080
Pragma: no-cache
Sec-WebSocket-Extensions: permessage-deflate; client_max_window_bits
Sec-WebSocket-Key: 8tJpUUPfH0byKGq0AgcUBA==
Sec-WebSocket-Protocol: v10.stomp, v11.stomp
Sec-WebSocket-Version: 13
Upgrade: websocket
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_10_0) AppleWebKit/537.36 (KHTML, like Gecko) Chrom
Response Headers view source
Connection: Upgrade
Sec-WebSocket-Accept: WFiCtNMveMhujOlLD4LuJKy1slI=
Sec-WebSocket-Protocol: v10.stomp
Upgrade: WebSocket


Elements Network Sources Timeline Profiles Resources Audits Console NetBeans
Preserve log Disable cache
Filter All Documents Stylesheets Images Media Scripts XHR Fonts TextTracks WebSockets
Name
Path
localhost
Headers Frames Cookies
Data
MESSAGE content-length:4 expires:0 destination:/queue/myQueue subscription:sub-0 priority:4 message
SUBSCRIBE id:sub-0 destination:/queue/myQueue
SEND destination:/queue/myQueue content-length:4 test
CONNECTED server:ActiveMQ/5.10.0 heart-beat:10000,10000 session:ID:Aruns-MacBook-Pro.local-492
CONNECT login:admin passcode:admin accept-version:1.1,1.0 heart-beat:10000,10000




chrome://net-internals/#events&q=type:SOCKET%20is:active
Events
capturing events (4641)
(?) type:SOCKET is:active
3 of 572
ID
Source Type
Description
1596087 SOCKET localhost:8080
1596088 SOCKET localhost:8080
1596381 SOCKET localhost:61614
1596381: SOCKET
localhost:61614
Start Time: 2014-10-23 10:30:37.952
t=143883 [st= 0] +SOCKET_ALIVE [dt=?]
--> source_dependency = 1596378 (CONNECT_JOB)
t=143883 [st= 0] +TCP_CONNECT [dt=0]
--> address_list = ["[::1]:61614"]
t=143883 [st= 0] TCP_CONNECT_ATTEMPT [dt=0]
--> address = "[::1]:61614"
t=143883 [st= 0] -TCP_CONNECT
--> source_address = "[::1]:57613"
t=143883 [st= 0] +SOCKET_IN_USE [dt=?]
--> source_dependency = 1596376 (HTTP_STREAM_JOB)
t=143884 [st= 1] SOCKET_BYTES_SENT
--> byte_count = 616
t=143885 [st= 2] SOCKET_BYTES_RECEIVED
--> byte_count = 164
t=143886 [st= 3] SOCKET_BYTES_SENT
--> byte_count = 89
t=143888 [st= 5] SOCKET_BYTES_RECEIVED
--> byte_count = 134
t=144739 [st= 856] SOCKET_BYTES_SENT
--> byte_count = 61
t=147073 [st= 3190] SOCKET_BYTES_SENT
--> byte_count = 54
t=147077 [st= 3194] SOCKET_BYTES_RECEIVED
--> byte_count = 196
t=153901 [st=10018] SOCKET_BYTES_RECEIVED
--> byte_count = 3
t=154226 [st=10343] SOCKET_BYTES_SENT
--> byte_count = 7

Debugging WebSockets



Filter: http | Expression... | Clear | Apply | Save

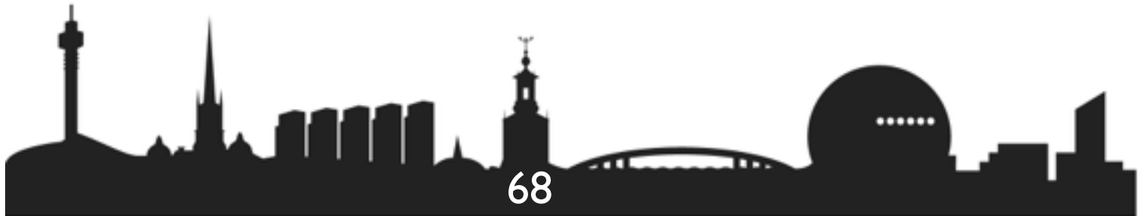
No.	Time	Source	Destination	Protocol	Length	Info
11	9.489449000	::1	::1	HTTP	648	GET /HelloWebSocket/ HTTP/1.1
13	9.491601000	::1	::1	HTTP	2134	HTTP/1.1 200 OK (text/html)
18	9.669322000	::1	::1	HTTP	501	GET /HelloWebSocket/echo HTTP/1.1
20	9.669489000	::1	::1	HTTP	543	GET /favicon.ico HTTP/1.1
22	9.670298000	::1	::1	HTTP	205	HTTP/1.1 101 Switching Protocols
24	9.671010000	::1	::1	HTTP	1624	HTTP/1.1 404 Not Found (text/html)
26	12.411987000	::1	::1	WebSocket	98	WebSocket Text [FIN] [MASKED]
28	12.413161000	::1	::1	WebSocket	108	WebSocket Text [FIN]
30	13.011122000	::1	::1	WebSocket	98	WebSocket Text [FIN] [MASKED]
32	13.013172000	::1	::1	WebSocket	108	WebSocket Text [FIN]

Production Tips

- Proxy can be evil and make WebSockets unusable
  - **Issue**: Remove "Upgrade" header
  - **Fix**: Set timeout, remove after `onOpen` called
  - **Issue**: Close connection after X idle time
  - **Fix**: Application-level heartbeat
  - **Issue**: Not allow to pass through at all
  - **Fix**: Fall back on long-polling

Production Tips

- Load Balancer
  - **Issue**: Don't work with WebSocket, e.g. Amazon ELB
  - **Fix**: ELB configured to use TCP, but no session affinity
- Browsers
  - **Issue**: IE 6, 7, 8, 9 and Safari 5 do not support WebSocket
  - **Fix**: Fallback using Atmosphere, Socket.IO, SockJS
- Inconsistencies in JSR 356



Atmosphere

- Java/JavaScript framework
- Portable asynchronous applications
- Fallback to long-polling in absence of WebSocket
- Containers: Netty, Jetty, GlassFish, Tomcat, JBoss, WildFly, WebLogic, Resin, WebSphere
- Browsers: Firefox, Chrome, IE (6x+), Opera, Safari, Android

https://github.com/javaee-samples/javaee7-samples/tree/master/websocket/atmosphere-chat

Resources

- Material: github.com/arun-gupta/nuts-and-bolts-of-websocket