The WebSocket Protocol

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Background

- Evolution of web apps
  - Dynamic and real-time application
  - Webmail, Chat, word processing, etc.
- HTTP is not designed for web apps
  - Large overhead
  - Hanging-GET is necessary for real-time server push

WebSocket is (1)

- New protocol over TCP
  - Opening handshake
    - HTTP-esque request and response
  - Newly defined WebSocket frame
- New API for JavaScript

```
var ws = new WebSocket("ws://example.com/foobar");
ws.onmessage = function(evt) { /* some code */ }
ws.send("Hello World");
…
```

WebSocket is (2)

- Intended to replace hanging-GET based bidirectional channel
  - Two XMLHttpRequest → One WebSocket

- Full duplex
- Smaller overhead
- Fewer TCP connection
- Simpler API

Other Requirements

- Coexist with HTTP on the same port
  - Use 80/443 which are rarely blocked
- Work with HTTP infrastructure
  - Proxy and firewall
- Allow cross origin connection
  - http://example.com/foo.js establish WebSocket to ws://example.org/chat
- Fit JavaScript programming model

Security Concern

- Cross protocol attack
  - Abuse of WebSocket on browser
    - By malicious JavaScript
    - To attack HTTP server, cache, …
  - Abuse of XMLHttpRequest
    - To attack WebSocket server
- Port scanning

Protocol Overview

- User-agent establishes TCP
  - Order, reliable transmission, congestion control are guaranteed by TCP
- Opening handshake
- Exchange WebSocket frames
- Closing handshake

Opening Handshake (1) Example

- Client sends

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

- Server replies with

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

Opening Handshake (2)

- HTTP compliant request/response format
  - Can go through intermediaries for HTTP
  - Code for HTTP can be diverted
- “GET /chat HTTP/1.1”
  - Requested resource is “/chat”
- “Host: server.example.com”
  - Enables name virtual hosting
- “Upgrade” and “Connection” header
  - Tells the server to switch to WebSocket protocol

Opening Handshake (3)
Peer Validation

- Check if the peer is WebSocket ready
  - Only ones understand WebSocket can generate valid Sec-WebSocket-Accept
- Challenge from client : Sec-WebSocket-Key
  - BASE64(Random 16 octets)
- Response from server : Sec-WebSocket-Accept
  - BASE64(SHA-1(concat <Key> and <GUID>))
    - SHA-1 is common, verifiable
    - GUID is uniquely defined for WebSocket
      - “258EAFA5-E914-47DA-95CA-C5AB0DC85B11”

Opening Handshake (4)

- Sec-WebSocket-Origin
  - Optional for non-browser clients
  - Server MAY check
- Sec-* prefix
  - Prevents cross protocol attack with XHR
- Cookie/Set-Cookie as well as HTTP
- Sec-WebSocket-Extensions and Sec-WebSocket-Protocol
  - Discuss later

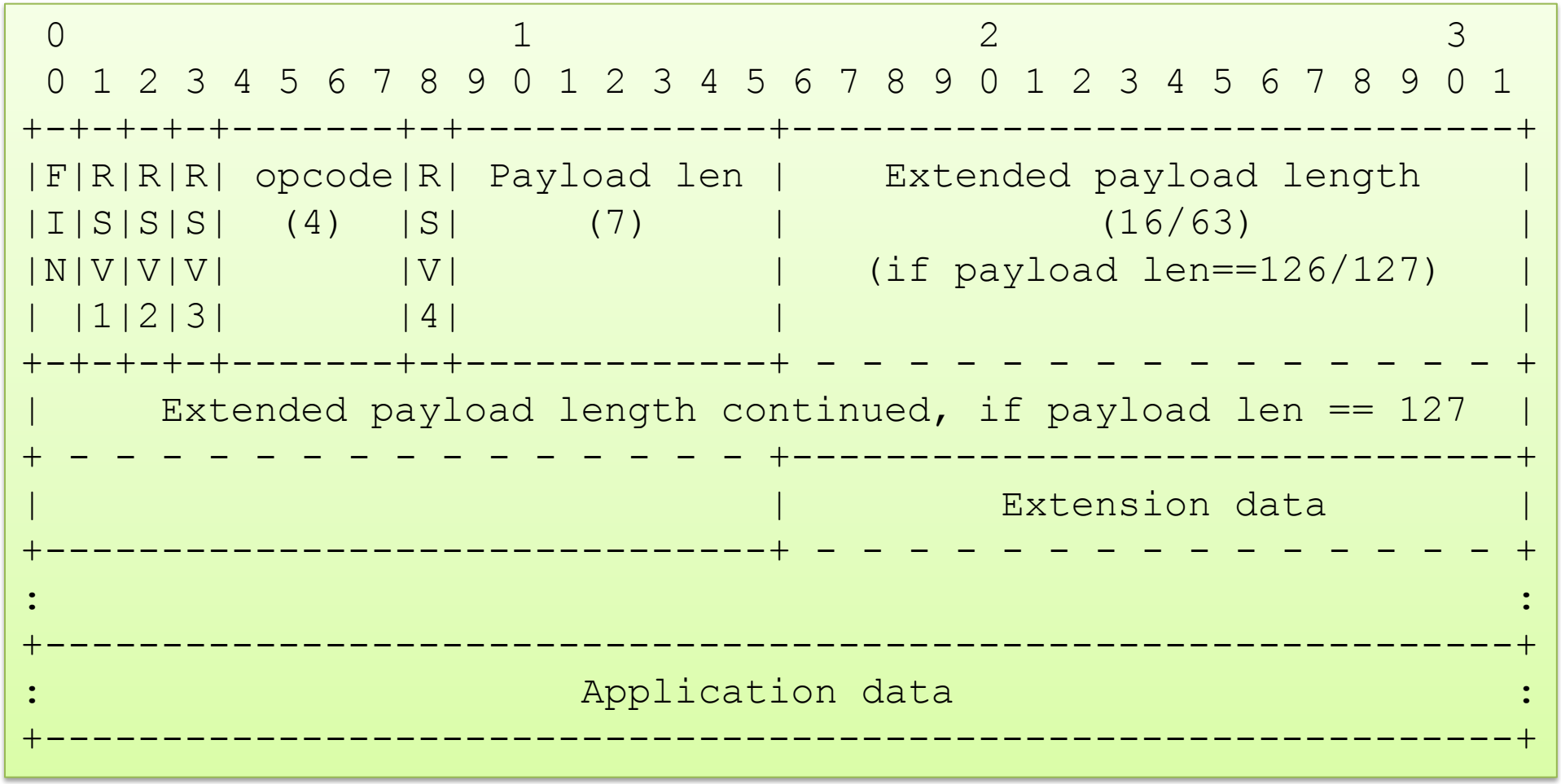
Framing (1)
Requirements

- Support binary payload
- Single framing for simplicity
  - HyBi 00 used 0x00 <UTF-8> 0xFF for text frame

→ Use payload length field for all type

- Some fields for frame type, extensibility

Framing (2)
Frame Diagram



Framing (3)
Requirements for Length Field

- Small overhead for small payload
  - Consider power sensitive mobile device
  - Short size like 8 bit is preferred
- Less fragmentation for large data
  - Big range like 64 bit is preferred

Framing (4)
7/16/63 Encoding

- At least 7-bit payload length field
  - 2nd octet of header = RSV4(1), payload_len(7)
- Extended payload length field may follow

- 0 <= payload_len <= 125
  - 7 bit
- 126 <= payload_len <= 2^16-1
  - 7 bit + 16 bit extended header
- 2^16 <= payload_len <= 2^63-1
  - 7 bit + 64 bit extended header

Framing (5)
7/16/63 Encoding

- 63 bit value + 1 bit padding =
  64 bit occupation
- Limit is set to 2^63-1 since some platform doesn't support unsigned 64-bit integer

- Example
  - 5 → 0x5
  - 256 → 0x7E 0x0100
  - 65536 → 0x7F 0x0000000000010000

Framing (6)
Opcodes

- 0x0 Continuation frame
- 0x1 Connection close
- 0x2 Ping
- 0x3 Pong
- 0x4 Text frame
- 0x5 Binary frame
- 0x7-0xF Reserved

Framing (7)
Room for Extension

- 4 reserved bits in header
  - RSV1, RSV2, RSV3, RSV4
- 9 undefined opcodes 0x7-0xf
- Extension data field

Framing – Open Issue

- Single opcode for control frames or
  Multiple opcodes for each control frames
  - Single control opcode
    1 leading octet of payload is control type
    - Easy to tell intermediaries the frame cannot be fragmented
  - Define the range of control opcodes
  - Multiple opcodes for each control type
- How to specify extension field length

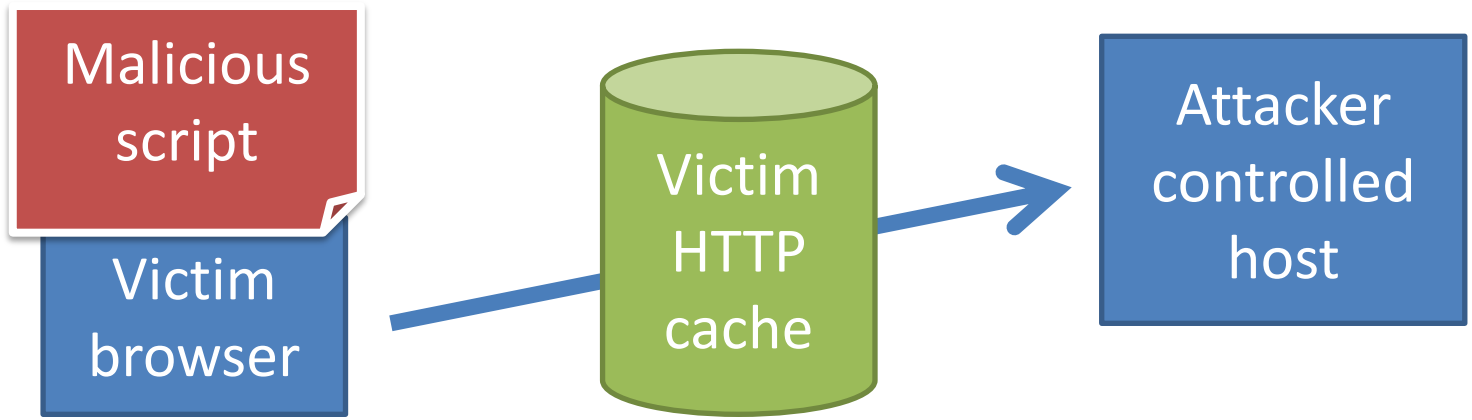
Ping and Pong

- Built-in ping
  - For keep alive, health check, …

- Alice send ping control
- Bob MUST reply with pong control with the same payload as received ping

Frame Masking (1) Background

- Security concern raised by Adam Barth



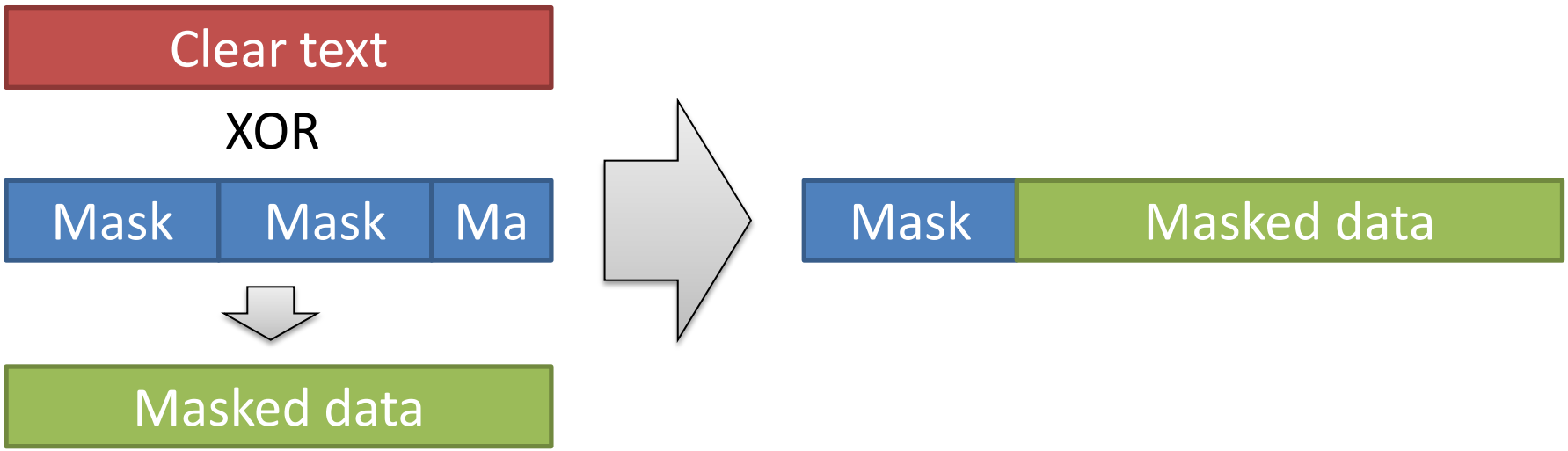

```
<WebSocket opening handshake string>
…some bytes…
GET /foobar.js HTTP/1.1
Host: example.com
…
Malicious data
…
```

Frame Masking (2) Background

- Intermediaries designed for HTTP may be poisoned
- Mask client-to-server frame
  - Prevent attacker controlled byte sequence from going over wire

Frame Masking (3)
Current Masking Method

- For each frame
  - Get 4 octets from cryptographically secure random number generator
  - masked_data[i] = clear_text[i] XOR mask[i % 4]
  - send mask and masked_data to server



Frame Masking – Open Issue

- Mask frame or mask payload
  - In-frame masking is less secure?
  - Making whole frame is bad for intermediaries?
- Mask only client-to-server or both direction
  - Debugging is easier if symmetric
- Mask extension field or not

Fragmentation (1)

- Enable sending part of message separately
  - Useful for dynamically generated contents
  - Flush partial data to vacate buffer
- Similar concept as HTTP chunked encoding
- Planned to be used for multiplexing

- Message : complete unit of data on app level
- Frame : network layer unit

Fragmentation (2)

- Use FIN bit and “Continuation” opcode

- Example
  - For message "abcdefg..."
  - Frame1
    - !FIN, opcode=<original opcode>, payload=abc...
  - Frame2
    - !FIN, opcode=CONTINUATION, payload=ijk...
  - Frame3
    - FIN, opcode=CONTINUATION, payload=stu...

Extension (1)

- Negotiate on opening handshake
- Modify payload or even whole frame
- Attach some information
  - as RSV1-4, new opcode or
    per-frame extension data field

Extension (2)
Negotiation Example

```
Sec-WebSocket-Extensions: deflate-stream
Sec-WebSocket-Extensions: mux; max-channels=4;
      flow-control, deflate-stream
Sec-WebSocket-Extensions: x-private-extension
```

- Applied in order the extensions are listed
- Server accepts part of requested extensions

Extension – Open Issue

- How to assign reserved bits and opcodes
- How multiple extensions interact
- Intermediaries are allowed to join/split fragmented frames with extension? How?
- Extension may consume unused opcodes?

Subprotocol

- Client may request subprotocol by Sec-WebSocket-Protocol header
- Server choose one from requested subprotocols and echo back it to accept

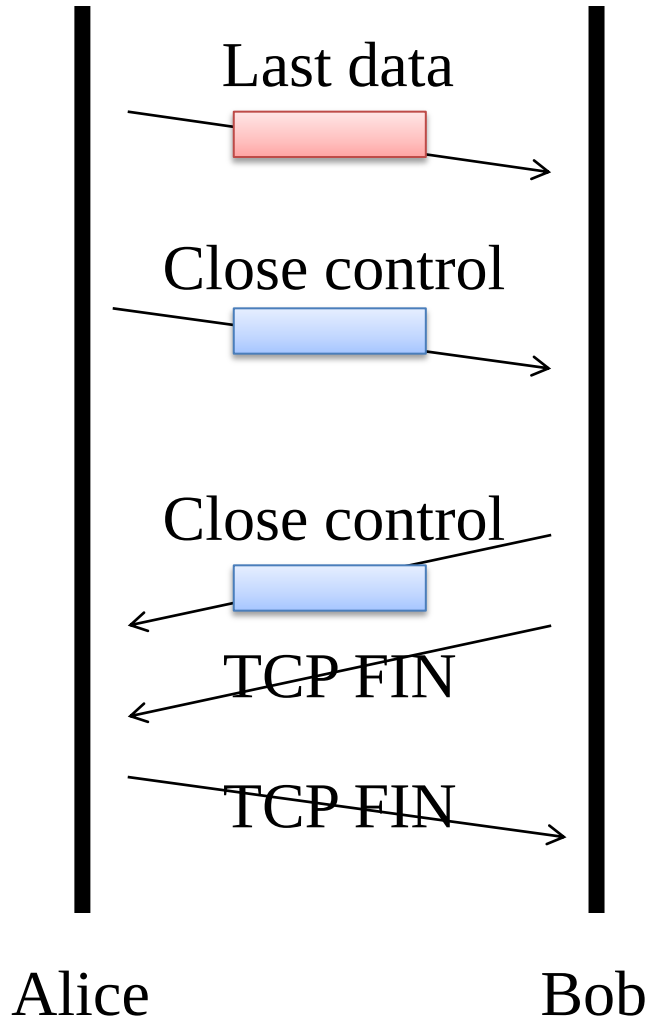
Closing Handshake (1) Background

- WebSocket is full-duplex
  - Peer may send a frame anytime
- RST hazard
  - A peer may close socket without reading out all received data from TCP stack
  - Cause sending RST
  - Peer may miss some data due to RST
- shutdown(SHUT_WR) is not available everywhere
- Implement safe-close on WebSocket layer

Closing Handshake (2)

- Alice sends close frame to Bob
- Bob sends close frame to Alice
- Bob closes socket
- Alice closes socket

- A peer can close TCP once both received and sent close



Closing Handshake (3)

- What this assures for Alice
  - Alice received all data sent from Bob
    - wasClean parameter of onclose handler
  - It's safe for Alice to close TCP connection
    - No more data coming from Bob → No RST hazard

- What this DOES NOT assure for Alice
  - Bob received all data sent from Alice
    - This requires 3-way close handshake

Status Code

- First two octets of close frame
- Not to be confusing, 4-digit code is used
  - while HTTP uses 3-digit code
  - Predefined codes
    - 1000 Normal closure
    - 1001 Peer is going away
    - 1002 Protocol error
    - 1003 Received unacceptable data
    - 1004 Too large message
- UTF-8 string may follow

Compression
Built-in extension - deflate-stream

- Applies 1951 DEFLATE to whole stream
- Simple
  - No negotiation parameter
  - No reserved bits, opcode, extension data
- Included for now to make sure we have at least one compression available

Compression – Open Issue

- Compress stream, frame or payload
  - Stream compression requires recompression when join/split/insert/filter frames
- More flexibility
  - Per-frame compression parameters
  - More compression algorithms

Gluing with JavaScript

- W3C The WebSocket API
  - http://dev.w3.org/html5/websockets/
- WebSocket class
  - send(), close()
  - onmessage, onclose, onopen, onerror
    - To prevent WebSocket from being abused for port scanning, no detail about error occurred during opening handshake will be reported

Gluing with JavaScript – Open Issue

- Specify how to handle error
  - If length field is bad : blah blah
  - If RSV1 is 1 : blah blah
  - Pass more information to onerror handler
    - As well as detailed status code now we have
- Interface for binary data handling
  - ArrayBuffer, Blob, …
  - Ian Hickson is working on this

Other Open Issues

- Keep alive
  - How to maintain underlying TCP connection
    - For long-living WebSocket
    - Have NAT, etc. remember it
    - Ping and pong
  - How to determine ping/pong interval
    - On opening handshake or by some control frame
      - How intermediaries interact

Other Open Issues

- HTTP compliance
  - “Fail on non-101” doesn’t comply HTTP
  - Support redirection
    - Possible security issue
    - Useful for load balancing
  - Reuse, retry of connection after handshake failure
- Multiplexing design