

Utilising peer-to-peer networking for data transfer over the browser

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Chapter 1

Project Scope

1.1 Aims and Objectives

The ultimate objective of my project is to investigate the plausibility of data transfer over web browsers (in particular, with file transfer and media streaming) without the need for a centralised client-server architecture, instead opting for a peer-to-peer network architecture. In order to do so, I plan to:

- Research peer-to-peer networking architecture and topologies
- Research WebRTC
- Research signalling protocols
- Research media streaming compression & protocols
- Research client-side JavaScript frameworks
- Develop a session signalling server in Java with the WebSockets protocol
- Develop a WebRTC Application to transfer and stream uploaded files.
- Implement a structured peer to peer network between peers transferring/streaming a file using the web application.

1.2 Stakeholders

The stakeholders involved in my project will be myself, my supervisor, Stelios Kapetanakis and the user.

1.3 Methods of Communication

Stelios and I have set up a regular meeting once a week on Friday at 4pm to catch up. On top of this, we communicate regularly via email and Stelios has access to a project git repository on GitHub and a workflow board set up on my web server to track the progress of my project.

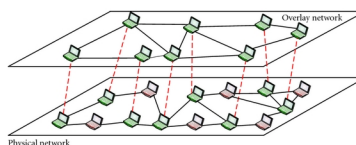
Chapter 2

Research

2.1 Comparing Network Architectures

Peer-to-peer networking is the distribution of resources and processing between the nodes of a network. These networks tend to take the form of an overlay network which is a topology describing a virtual network that sits on top of a physical network (e.g the internet) consisting of a subset of the nodes connected to the physical network.

Figure 2.1: An Unstructured Peer-To-Peer Overlay Network [1]



Although an overlay network does not need to manage the burden the physical network is responsible for, in order to discover and route new nodes, it needs to have some way of managing the subset of nodes using it. There are several different ways of defining how it does this:

- Unstructured peer-to-peer: Peer connections in the overlay are established randomly and do not adhere to a network topology. New peers copy the connections another peer has formed and develops its own over time.[2]. These networks are easier to build than structured networks as routing is random and they also tend to fair better in periods when the rate of peers leaving and joining (churn rate) is high due to their non-deterministic nature. However, searching in these networks tends to be less efficient as they rely on flooding the network to find nodes that have the data they are searching for.
- Structured peer-to-peer: Peers in a network are organised in a specified network topology and generally use a distributed hash table (DHT) to link together. The DHT consists of many peers maintaining a partial hash table referencing the unique keys of other peers in the network, allowing it to route to them. This way, a peer can communicate with another by hopping messages through peers in their hash table. Generally, each peer's hash table consists of nodes getting exponentially further away from it in order to improve the efficiency of this process. [2].
- Hybrid peer-to-peer: A combination of peer-to-peer and client-server models, these networks use centralized servers in some way. This model tends to work better than both unstructured and structured as dependent on how it is implemented, features that function better in decentralized networks can be left to the peers in network whilst the server can handle the features it is better at. [3]

Additionally, there is also the client-server model. In a basic sense, this is when the machines processing data (servers) are distinct from the computers requesting this processing (client), although in actuality, the

boundaries between them vary dependent on how it is implemented. Whilst the shift of processing on to the service supplier means that the user of the application does not need a powerful machine to run it, it also means that the service supplier has the responsibility of maintaining and paying for these servers. Furthermore, although modern server architectures are designed in a distributed structure granting them to be more robust (as distribution allows for redundancy and load balancing), if these servers undergo too much load or in extreme cases, if the server farm completely crashes, the user would not be able to use the application as intended.

Using a peer to peer architecture avoids the issues associated with the client-server model as processing is distributed between the nodes making up the network, resulting in it being cheaper to maintain as there is less reliance on servers and more robust as the network scales as load increases. However, there are a number of considerations to be aware of in peer to peer networking, the largest of which being security as there is no centralized authority to manage access control to resources. Thus, a malicious client could potentially launch a number of attacks versus other nodes in the network such as Denial Of Service (DoS) where a malicious group of nodes floods a network with a massive amount of fake data, potentially crashing nodes within it or Man in the Middle (MitM) attacks where a node is able to intercept data flowing between two other nodes and spy on or poison this data[4]. Whilst it would be hard to completely avoid risks like this as it is an inherent flaw in peer-to-peer architecture, introducing the basic concept of trust into a peer-to-peer network can stop malicious peers from entering it in the first place. This will be implemented in my application by allowing users to enable authentication (via password) for the uploaded file potentially preventing malicious attackers from being able to download or stream it.

My application will most closely resemble a hybrid peer-to-peer network as even though the actual channel for transferring data between peers (WebRTC Data Channel) will not go through a server, it will use a signalling server to route peers together. To form a network of peers that go beyond the one-to-many peer connection established by WebRTC, the signalling server in conjunction with the client-side application will have to manage how these peers connect to each other. A way of doing this is to connect new peers to the second newest peer and so on, forming a linear chain of peers that can reroute if the neighbouring peer disconnected.

Figure 2.2: Linear network

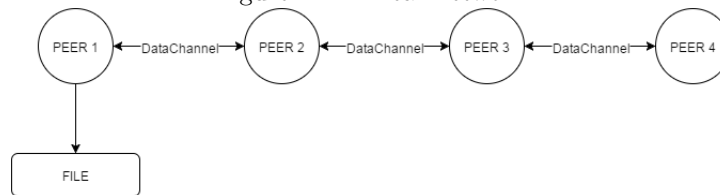
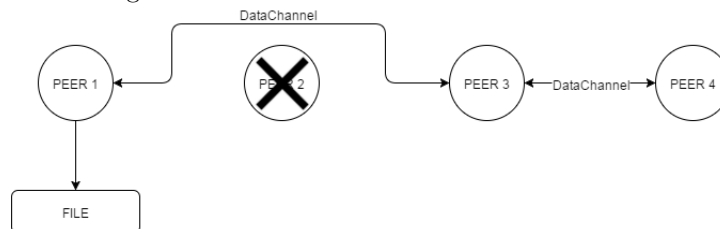


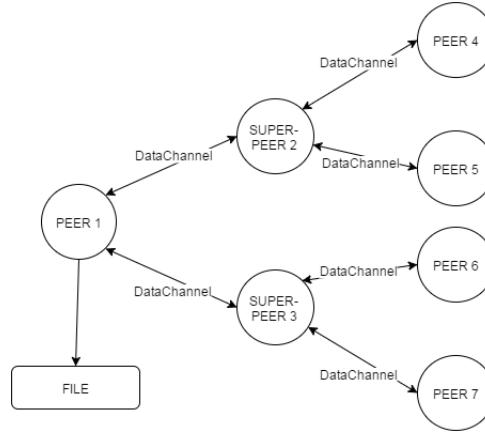
Figure 2.3: Peer disconnects from the network



However, this would prove inefficient if a peer in the chain malfunctioned or restricted bandwidth, potentially bottlenecking the rest of the peers behind it. As an alternative, peers could be routed based on a tree network topology [5] consisting of supernodes, "high capability" nodes that relay the transferred data to subnodes. This way load can be balanced across many nodes by distributing new nodes to another supernode or by electing further supernodes if it increases too much or if one disconnects. By exploiting heterogeneity between peers of the network, this topology can also be used to improve performance within the network by electing supernodes based on criteria such as location and, in our case, how much of the

data has already been transferred or streamed to them. By doing so, performance within a network can potentially be improved as subnodes can be connected to supernodes based on this criteria, e.g if a subnode is located in the same place as a supernode then use it.[6].

Figure 2.4: Tree Network



2.2 Current Solutions to Data Transfer

Currently, solutions such as DropBox and Google Drive focus on cloud storage as a service whilst providing the ability to transfer data as a secondary function of this service. Although this is an extremely valuable and convenient idea enabling consumers to back-up their data, not all want a third party service that stores the data they want to transfer as this practice does raise ethical issues, namely with the data's security, privacy and ownership once it has been uploaded. However as a consumer, this can be hard to avoid when the online storage and transfer of data are so closely intertwined as these services have a huge market share.

Once you have uploaded files to one of these services, there is a trust placed on the company to store the data securely. However you could argue that this trust is misplaced, in 2010, the "Cloud Security Alliance" released a regularly updated list of the top threats faced by cloud computing services submitting there are numerous security issues faced within the cloud computing industry with many of the issues on this list occurring due to malicious intentions. For example the 6th item on the list, "Malicious Insiders" describes a situation in which current or former employees abuse their authorizations within system to gain access to sensitive information [7]. This suggests that even though companies can protect their client's data to an extent, there are still issues the industry face that consumers may want to avoid.

Whilst the uploaded data can be encrypted in a way that means only clients of the service can decrypt it (through end-to-end encryption), many people feel insecure leaving traces of their private information on a remote server belonging to a company that is not necessarily always acting in their interest. In 2013, this concern was legitimized by Edward Snowden when he disclosed information about government surveillance programs such as PRISM that coerced firms such as Google, Microsoft and Yahoo to provide private consumer data from their services to the government.[8] More recently, this idea has been reinforced by legislation such as the "Investigatory Powers Bill" being introduced in the UK that could prohibit companies from using end-to-end encryption techniques allowing authorities to request decrypted client data [9]. Whilst we can assume they have done this with non-malicious intentions, by weakening the encryption practices of these companies, they will potentially weaken the defence against malicious attackers.

As an alternative to using cloud storage solutions for sharing files, there is also specific data transfer sites such as WeTransfer that allows you to send files up to 2gb via their site. This works by sending a link through email to the person you want to send the file to. Whilst it does store the uploaded files, they are only kept for 7 days in order to prevent unnecessary storage costs [10]. Although this is better for data privacy, WeTransfer use third party providers such as Amazon Web Services (AWS) to store this data using AWS S3 Storage [11] meaning there is still the potential concern of data privacy and security highlighted previously.

Peer-to-peer networks also been popular for file sharing since the late 1990s due to the rise of applications such as Napster which focused on peer to peer music sharing. Napster worked by using a central server to index files that each peer made available on their machine. Each peer would then be able to search the index for copies of songs and download them from each other. However, this service was eventually shut down as the company ran into legal problems with copyright infringement. Since then, protocols such as BitTorrent have improved on the idea of peer to peer sharing. The BitTorrent protocol works by peers creating ".torrent" descriptor files that describe the file's metadata, this is then shared however it is seen fit. Each peer wanting to download this file then picks up this ".torrent" file, opens it with a BitTorrent client and joins a "swarm" of peers, becoming one of the many "leechers" downloading this file. At the same time, this peer becomes one of the many "seeders" uploading this file as they download it so that other leechers can download it from them. The initial peer discovery is based on "trackers", servers hosting lists of seeders and leechers for the file. One of the issues with BitTorrent is that in order to share a file, you must go through the process of downloading a client, creating a ".torrent" file, adding it to a trackers list and sharing the ".torrent" with your peers and this can be seen as a arduous task for a basic consumer looking to share their files. Another problem is that if a tracker is compromised, there is potential for malicious attacks using the information stored on there.

As an alternative to these current solutions, the application I plan to develop has the aim of separating the online transfer of data from it's storage by connecting the peers involved in the transfer directly with each other. This circumvents the problems with cloud storage as the data being transferred does not pass through any servers as well as the problems with current peer to peer file sharing as it does not require a desktop client or torrent files. To allow my application to share files online, WebRTC will be used.

2.3 WebRTC

WebRTC (Real Time Communication) is an emerging web technology that enables browsers to communicate real time via a peer-to-peer connection, avoiding the need for a centralized server to transfer data between clients. This was first released by Google as an open source project in May 2011 [13] and was later drafted as an API definition by W3C remaining as a work in progress. [14]. WebRTC has yet to be fully implemented in every web browser but Chrome, Firefox and a WebRTC specific browser called Bowser do support it. Firefox (Nightly), in particular seems to be leading the way in this so the application will specifically be developed towards this browser[15]. The 3 main WebRTC APIs supported at this time are:

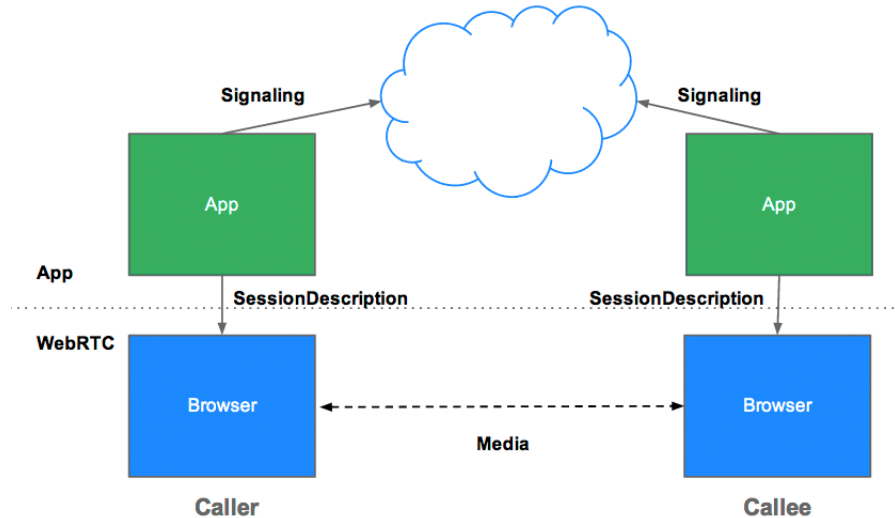
- **RTCDataChannel:** "The RTCDataChannel interface represents a bi-directional data channel between two peers of a connection." [16]
- **RTCPeerConnection:** "The RTCPeerConnection interface represents a WebRTC connection between the local computer and a remote peer. It is used to handle efficient streaming of data between the two peers." [16]
- **getUserMedia:** "Prompts the user for permission to use one video and/or one audio input device such as a camera or screensharing and/or a microphone. If the user provides permission, then the successCallback is invoked with the resulting MediaStream object as its argument. If the user denies permission or media is not available, then the errorCallback is called with PermissionDeniedError or NotFoundError respectively. Note that it is possible for neither completion callback to be called, as the user is not required to make a choice." [16]

In order to achieve it's aim, the application will utilize the RTCPeerConnection and RTCDataChannel APIs. The former to establish a peer connection between two clients and to stream whilst the latter will be used to create a data channel over this peer connection to transfer data.

As mentioned in the Javascript Session Establishment Protocol (JSEP) [17], although WebRTC and the browser is used to transfer the data between two peers, it purposely does not handle signalling. This is a concept that came from telecommunications and utilised in VoIP and is the process of organising the communication between two clients, handling the exchange of metadata that creates and manages a session. The rationale behind WebRTC being signalling protocol-agnostic is that different applications will require

particular protocols in order to, for example, fit into previously existing architecture. In the case of my application, to handle signalling, Session Initiation Protocol (SIP) over WebSockets will be used.

Figure 2.5: WebRTC Architecture as defined by JSEP [17]



WebSockets is a protocol implemented by browsers and servers to provide bi-directional communication between them[18]. Once established, a session with a client communicating with the server is left open for the server to send messages to the client and vice versa, making it a good candidate for signalling with a WebRTC application which needs peers to be able to reliably send messages back and forth through the server. Over this WebSockets session, SIP messages will be sent. SIP is a communication protocol that does not specify how signals are transported but how these signals are defined. The transaction model defined by SIP is similar to HTTP with each SIP request being matched by a SIP response. An example of a SIP over WebSockets transaction:[19]

Initial handshake with WebSockets signalling server over HTTP
 Alice -> proxy.example.com (TLS)

```

GET / HTTP/1.1
Host: proxy.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
Origin: https://www.example.com
Sec-WebSocket-Protocol: sip
Sec-WebSocket-Version: 13

```

Switching to WebSockets protocol
 proxy.example.com -> Alice (TLS)

```

HTTP/1.1 101 Switching Protocols
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+x0o=
Sec-WebSocket-Protocol: sip

```

SIP REGISTER request letting the server know of Alice's "location"
 Alice -> proxy.example.com (TLS)

```

REGISTER sip:proxy.example.com SIP/2.0
Via: SIP/2.0/WSS df7jal23ls0d.invalid;branch=z9hG4bKasudf
From: sip:alice@example.com;tag=65bnmj.34asd
To: sip:alice@example.com

```

```
Call-ID: aiuy7k9njasd
CSeq: 1 REGISTER
Max-Forwards: 70
Supported: path, outbound, gruu
Contact: <sip:alice@df7jal23ls0d.invalid;transport=ws>
;reg-id=1
;sip.instance="urn:uuid:f81-7dec-14a06cf1>"
```

OK response

proxy.example.com -> Alice (TLS)

```
SIP/2.0 200 OK
Via: SIP/2.0/WSS df7jal23ls0d.invalid;branch=z9hG4bKasudf
From: sip:alice@example.com;tag=65bnmj.34asd
To: sip:alice@example.com;tag=12isjln8
Call-ID: aiuy7k9njasd
CSeq: 1 REGISTER
Supported: outbound, gruu
Contact: <sip:alice@df7jal23ls0d.invalid;transport=ws>
;reg-id=1
;sip.instance="urn:uuid:f81-7dec-14a06cf1">
;pub-gruu="sip:alice@example.com;gr=urn:uuid:f81-7dec-14a06cf1"
;temp-gruu="sip:87ash54=3dd.98a@example.com;gr"
;expires=3600
```

Once two peers have registered, one of them can send an invite to another through the server in the form of an INVITE request to form a signalling channel between them which WebRTC uses to establish a peer connection and data channel. To create this peer connection, it uses interactive connectivity establishment (ICE) to find a list of the possible IP's and ports of each peer which are then sent through the server. Once this is done, the data channel can be formed and packets can be sent peer-to-peer. These packets are managed and secured by Secure Real Time Transport Protocol (SRTP) for media and Stream Control Transmission Protocol (SCTP) for non-media and encrypted by Datagram Transport Layer Security (DTLS) [20].

Chapter 3

Specification

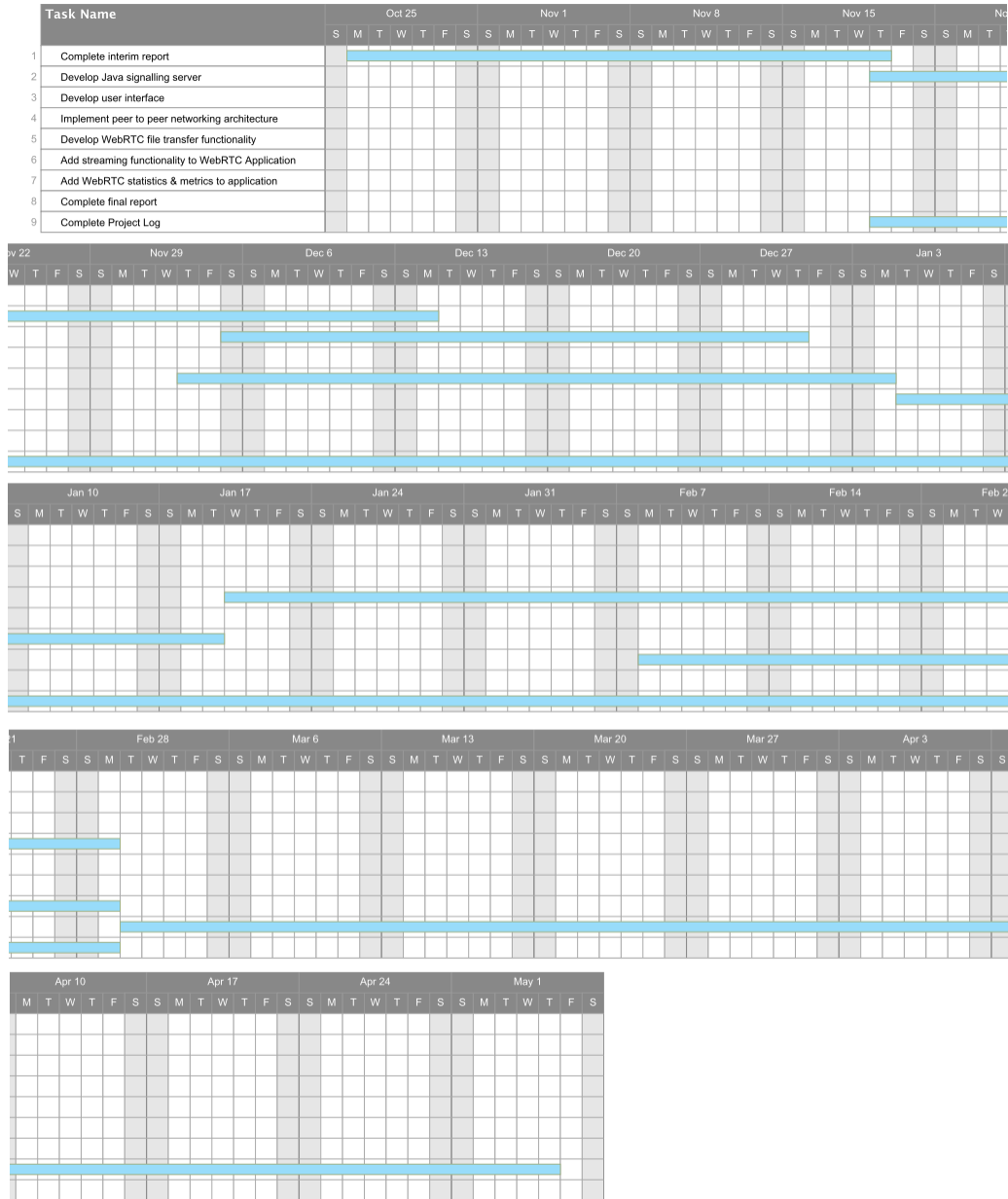
3.1 Deliverables

The first intermediate product will be the signalling server written in Java. This will handle the exchange of client meta data in order to establish the connection between two peers using the web application. I plan to overlap the development of this with the development of the data transfer functionality and user interface of my second deliverable, the web application as manually testing the signalling server will be a lot easier with a partially developed application to test it with.

The first end deliverable will be the client side web application the user interacts with in order to select a file as well as handling sending the meta data to the signalling server and managing the peer-to-peer data transfer and media streaming. This is broken down into several intermediate products, the data transfer functionality, the media streaming functionality, the peer-to-peer network and the user interface. I plan to produce the data transfer functionality first along side the user interface to allow for manual testing. After I have implemented data transfer, I will work on media streaming and forming the peer-to-peer network topology.

The second end deliverable will be the final report containing documentation and analysis using the metrics from my application, comparing how it and technologies behind it perform in comparison to others, focusing in particular on how peer-to-peer over the browser (WebRTC) compares to other methods of data transfer and media streaming.

Figure 3.1: Schedule of Activities



3.2 Risk Analysis

Risk	Probability (1-5)	Impact (1-5)	Mitigation	Contingency
Illness/Injury	4	3	Reserve time for illness Be hygienic Eat healthy Exercise	Allow time for recovery Take medicine to aid recovery
Inaccurate estimations	3	3	Be liberal with estimations Reserve time for deliverables behind schedule	Adjust scope of project
Data loss	1	5	Use a version control system Keep local backups	Recover data from Git
Uncommunicative stakeholder	1	3	Ensure regular meetings with stakeholder	
Stakeholder turnover	1	4	N/A (out of my control)	Get new stakeholders
Project scope too large	3	4	Research enough to be certain in project scope Be liberal with estimations	Adjust scope of project
Technologies too immature/insufficient for project	2	4	Research technologies beforehand	Find alternative technologies Adjust scope of project

3.3 Quality Analysis

The main measure of success will be the web application's performance in it's ability to transfer & stream data between two peers. To track this, I will implement metrics using the WebRTC "getStats" statistics API, which allows for monitoring of the bandwidth usage, packets lost and network delay within a data channel between two peers. I will then gather these statistics in two different cases, one where there is no formal network structure (to find a baseline) and then when the many-to-many network has been implemented to compare if the structured peer-to-peer network does improve performance of the application. This network will also have it's own monitoring to ensure that peers are being correctly organised. Further to this, I will also compare the speeds of file transfer with other services such as DropBox through their API, however this may prove unrealistic as these services will be running on more powerful servers. To certify that the user-experience is acceptable, the application will also be user-tested. The signalling server will be load tested in isolation to make certain it can handle multiple requests to ensure it does not bottleneck the application.

Chapter 4

Methodology

I chose to use an alternative methodology to the waterfall model because it lacks the ability to adapt to changes in a project deadline. Due to the way waterfall is structured into different phases that must be completed sequentially, often when changes such as new requirements occur, all these phases must be repeated in order to account for this. Iterative methodologies take an approach that can adapt to these changing requirements because they utilise short development cycles and focus on developing small modules of a product at one time, making it easier to revise a product if necessary. This is particularly useful in my project as it is relatively experimental and the requirements of it may change regularly.

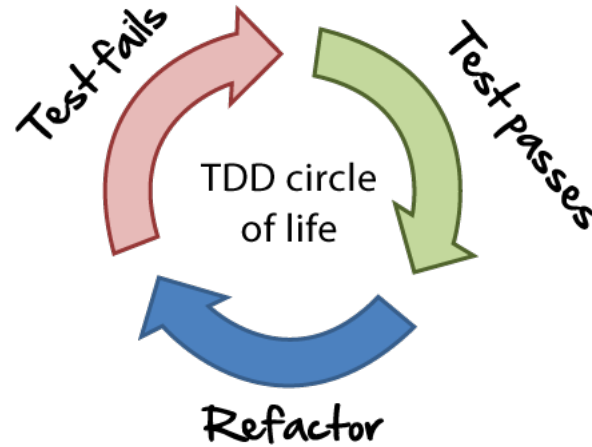
Thus, as a way of tracking the progression of my project, I plan to use an iterative and evolutionary methodology. This is used within software development as a way of incrementally developing applications through small cycles. Whilst it will be similar to scrum, it will not have the stricter framework surrounding it that requires a product owner and scrum master. This methodology will be relatively simple and based around a backlog of tasks from which a developer pulls from in a limited amount, normally 1 or 2 tasks at a time which will then be pushed through the development work flow.

In my case, the work flow will be relatively simple:

1. To Do
2. In Progress
3. Code Review
4. Manual Testing
5. Done

During the "In Progress" step of the work flow, I will use a test driven development (TDD) process in which tests are written first and then code is written to make the test work. However, I will be fairly lenient with this, only using this process on parts of the code that require stringent testing as writing unnecessary tests will take up development time.

Figure 4.1: Test-Driven Development (TDD) Cycle [21]



During the "Code Review" step, I plan to self-evaluate the task I have completed. On top of this, I will run static code analysis tools (such as FindBugs/PMD for Java) if the task is a coding task and use the code review section StackExchange to get second opinions. If it passes the code review step and it is possible to do so, I will black-box test the task from a user's perspective to see that it actually works as intended. Once every task forming a feature is completed, I will manually test the feature as a whole to see that each task has integrated together as planned.

To visualise this workflow, I will use the open source web application "Kanboard" which I have hosted on an Amazon Web Instances EC2 Instance. This will allow me to keep track of progress throughout the duration of the project. To manage the actual changes made to the project files, I have utilised the version control system Git with a private GitHub repository containing my project.

Chapter 5

Prototyping

5.1 Signalling

5.1.1 1st Iteration - Spring Boot

Spring WebSockets Over STOMP

The first prototype of the signalling server for Transfer4me was implemented using spring boot. This is a part of the Spring application framework emphasising convention-over-configuration, making it faster and easier to produce a working prototype. To support the WebSocket protocol, Spring uses the "STOMP" sub-protocol to model the message sent between server and client, STOMP is very similar to HTTP in how it models the message but is sent over TCP once the socket is established. Using the STOMP JavaScript client, an application can subscribe to several destinations and listen for events (by asynchronous callbacks) or publish events using a send method that takes a string identifying the event (which in this case is "signal") and another string representing the message. The architecture that was created on top of this protocols used rooms that were created when a user uploads a file designated via a URL which the recipients then subscribe to when they load the page.

To create the room that the users reside in, the client that uploads the file fires a request to the server using an endpoint independent of WebSockets. When the server receives this request, it generates a Room object and a random unique integer that serves as its identifier. This room is then added to a list of rooms and the Id is returned to the client in the response. The uploader then uses this id to subscribe to the room over WebSockets. When this connection is established, the server creates a user object and adds it to the correct room. This ID is then appended to the base URL of the page for the uploader to share. The recipient then loads the URL but only joins the room at the point at which it is necessary (when the recipient either chooses the download or stream button), This is a tactic called "Lazy initialization" and by using it, the server only has to cope with the load from the sockets that actually need to be connected as opposed to users that may be idly sitting on the page.

Problems

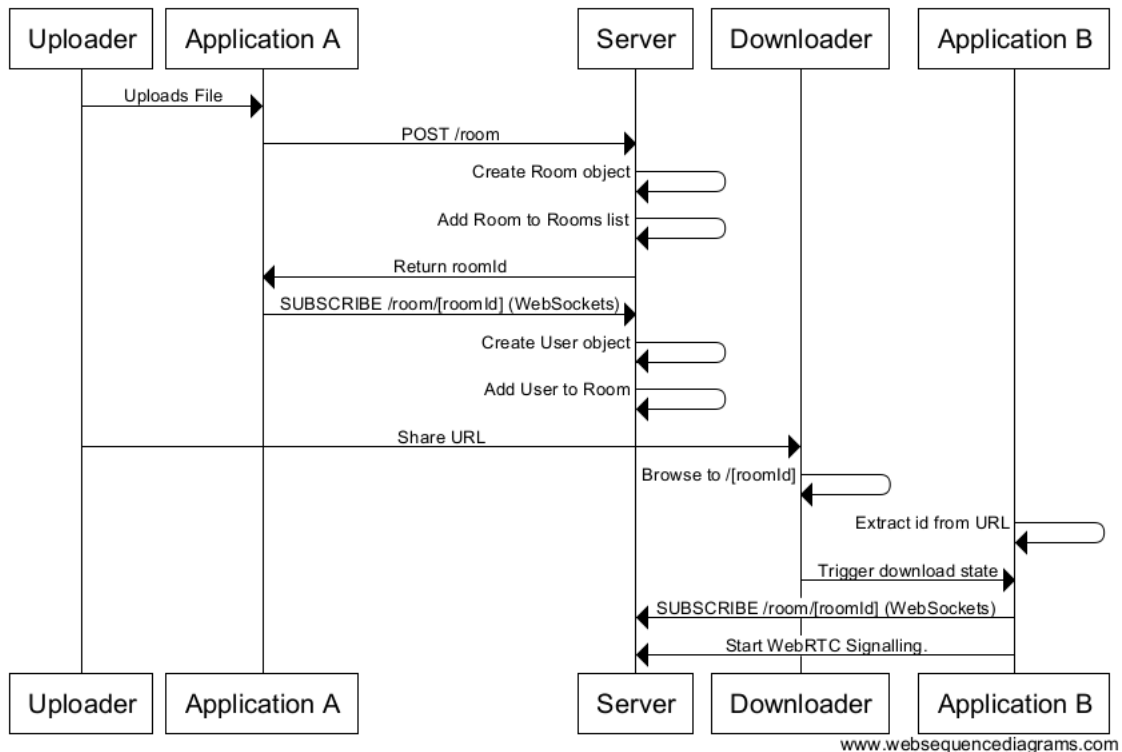
The main problem I found with the Spring implementation was in its limited functionality. It was extremely hard to implement sending messages to individual specific sockets which limited how multiple peer connections could communicate within the same room as they would all be receiving every signal being exchanged. This could be avoided by making each client application only use the messages that were destined for it by appending an identifier to each message but that would not stop the clients from receiving the messages, only how they used them. As a result, this is not a viable solution as it leaves the application open to man in the middle attacks as a user could easily modify the client-side application to log all of the messages that it received which is a major issue in this case where the the majority of the messages sent will be WebRTC meta data containing information such as your IP address.

5.1.2 2nd Iteration - Node JS

Socket.IO

To solve the problems found with the Spring implementation, the server was refactored using Node.js as a replacement. This is a server-side environment that uses modules written in JavaScript to produce web applications. In my case, choosing this environment gives me the benefit of developing the full stack in one language, making the process a lot easier. Node.js maintains support for WebSockets through the Socket.IO library which offers extended functionality over the Spring counterpart. Socket.IO models communication using the concepts of "rooms" and "namespaces" where a namespace is represented by the endpoint a socket connects to and rooms are channels within this that users can be a part of, allowing for communications to be separated. By default, every socket that connects to a namespace has it's own room which means Socket.IO can broadcast events to specific user's rooms solving the security issues that I was unable to with the spring implementation. As a result of this, the architecture of the server was slightly changed to reflect this new functionality as there was no longer a need to have an object to specifically represent a user.

Figure 5.1: Signalling establishment sequence



API

At this point, the API was extended order to support the changes in the client side web application's interface. Another endpoint was added to retrieve the file type of the file uploaded as the application would let you select the stream option for any file (including files such as a text document) which would evidently cause it to break. By adding this endpoint, it meant that the client-side application could find out the file type and only present you with the corresponding options for this file type. It was also extended to provide basic authentication by modifying the current new room endpoint to generate a password if specified and adding a new endpoint to validate the password. As these endpoints were added, I realised that they were becoming inconsistent and should be structured with more consistency. As a result, they were re-factored using a RESTful approach. REST (Representational State Transfer) is an architectural style specifying that an endpoint into a system (such as a URI) should be built around resources with methods for retrieving and

manipulating this resource. In the real world, these methods generally translate into HTTP verbs such as GET and POST. For example to add a room, a POST request is sent to the URI `"/room"` with the body data containing the options and to retrieve a room, a GET request is sent to `"/room/roomId"`. These guidelines allow for an easily maintainable API as well as providing the client web application with a predictable and consistent group of URIs to code against. As a RESTful API is modelled in terms of resources, it does not hold the state of a client's journey throughout the web application and thus, this is left up to the client consuming the resource which in this case is a JavaScript application. By doing so, it means the server is under less load and is in a better state to be scaled.

5.1.2.1 JSON

Both the socket implementation and the API transfer data in a format known as JSON (or JavaScript Object Notation) in order to remain consistent throughout the application. This was chosen as the data transfer language because JavaScript has native functions for parsing to and from JSON as opposed to other common alternatives such as XML, I also found that JSON is a lot easier to read as a human than XML and the benefits of XML such as custom schema support was not deemed necessary.

5.2 Peer to Peer Communication

5.2.1 One-to-one peer connection

As a starting point, I worked on using WebRTC to establish a simple peer connection between two clients. This process is done through negotiation using offers and answers representing what each client wants from the other client and what the client is willing to offer such as media streams and constraints on these. These parameters are modelled using a protocol called "Session Description Protocol" or "SDP" and is generated by WebRTC. In a traditional WebRTC architecture, the peer that sends the offer tends to have something to offer (such as a stream). The architecture for transfer4me is slightly different in this sense as the offer is sent from the recipient even though the uploader is the client with something to offer. This arises from how transfer4me uses WebRTC as a means to transfer files as opposed to its conventional purpose of establishing real-time communications. Due to this, the negotiation process is closer to reflecting the "request-response" pattern used in HTTP transactions more than it does an "offer-answer" model. This architecture also improves performance as the uploader does not have to send and maintain offers to every recipient that joins the room which would put them under a significant amount of unnecessary load especially if the recipient never downloads or streams the file. Instead, the offer is "lazily initialized" by the recipient in the sense it is only created and sent at the point it is needed which in this case is when the recipient either downloads or streams the file, this way the uploader only deals with the recipients as and when they need the file.

Once the offer SDP is created, it is stored as the local description and sent to the uploader via the signalling channel. The uploader receives this, sets it as the remote description and creates an answer SDP which is again set as their local description and sent back to the recipient via the signalling channel. Both these SDPs contain "ICE candidates" which detail potential IP addresses that can potentially be used to establish a connection. However, how WebRTC handles the retrieval of these ICE candidates depends on the browser. Chrome supports a concept called "trickle ICE" where ICE candidates can be sent on-the-fly as they are received regardless of whether the sdp has been sent or not whereas Firefox is limited as it does not support this and all candidates have to be sent with the sdp.

Figure 5.2: Peer Connection Establishment Sequence in Chrome

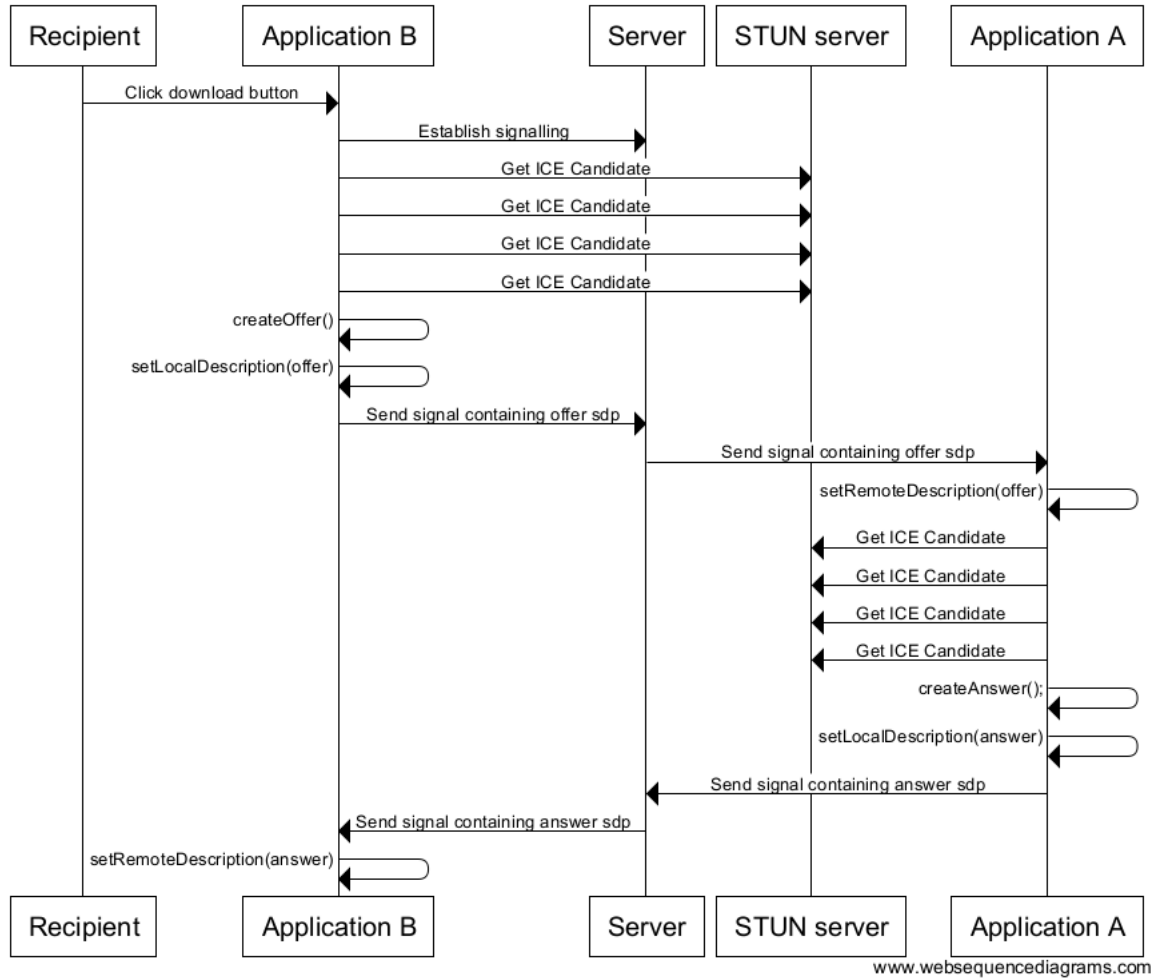
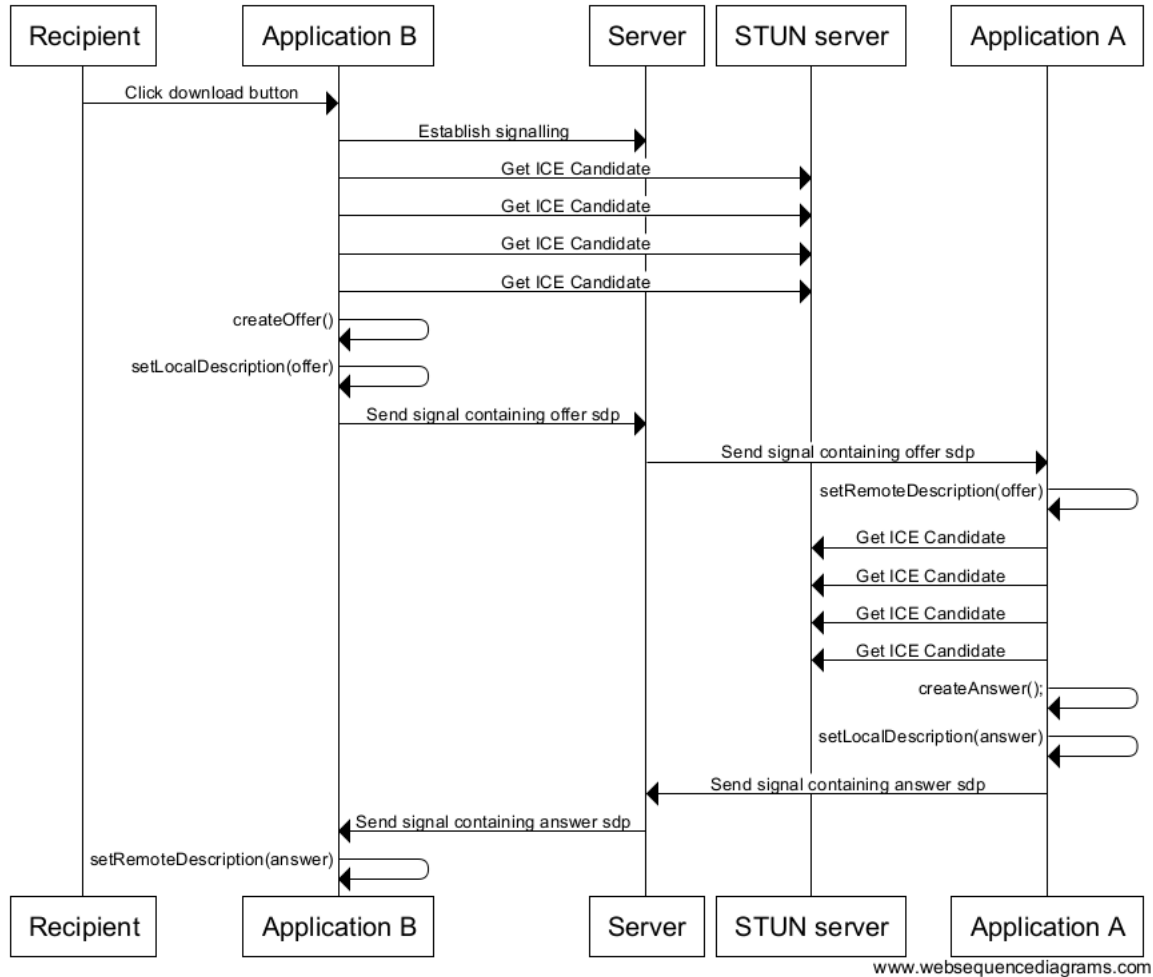


Figure 5.3: Peer Connection Establishment Sequence in Firefox



5.2.2 Using RTCDataChannel to transfer files

In order to download a file, the recipient creates a new `DataChannel` using the `RTCPeerConnection` API which is added to the offer to be sent to the uploader. Once the connection is established, the uploader waits for the addition and establishment of this `RTCDataChannel` via an asynchronous event listener. After this, how the file is sent depends on the browser. In Firefox, once the `DataChannel` is established, a callback is fired which sends the file through. On the recipient-side, an event listener waits for messages to be sent through the `DataChannel`, once the file is sent through, it is caught by the listener and is downloaded. However, Chrome has a limit on the size of the messages that can be sent through `RTCDataChannel` which means the file has to be chunked, slicing a file down into several smaller parts. Although this takes longer, it does have advantages such as allowing a file download to be resumed from a specific point if an error occur. At this point in the development process, I decided to specifically aim towards Firefox as the browser to code towards due to the size limit in Chrome.

Figure 5.4: File sending sequence in Chrome

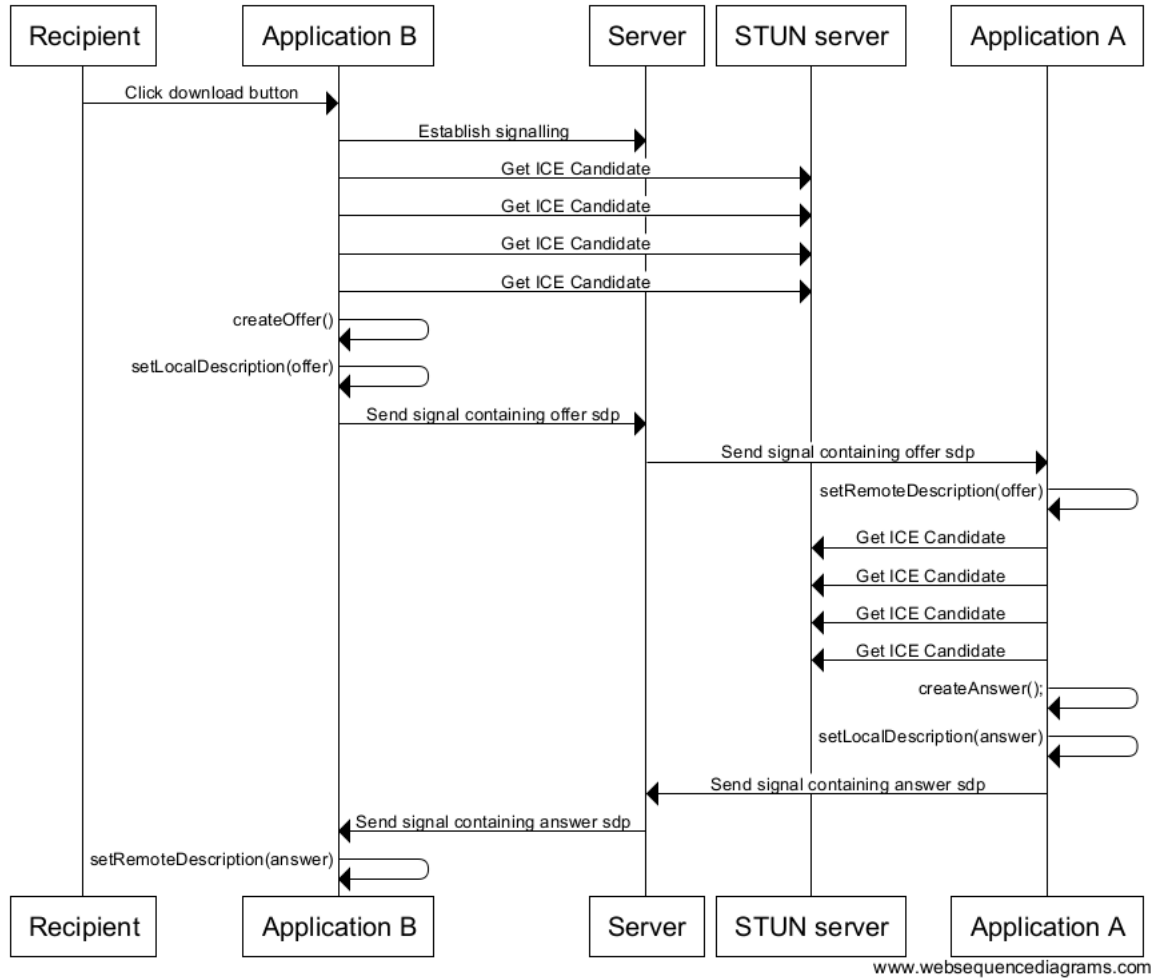
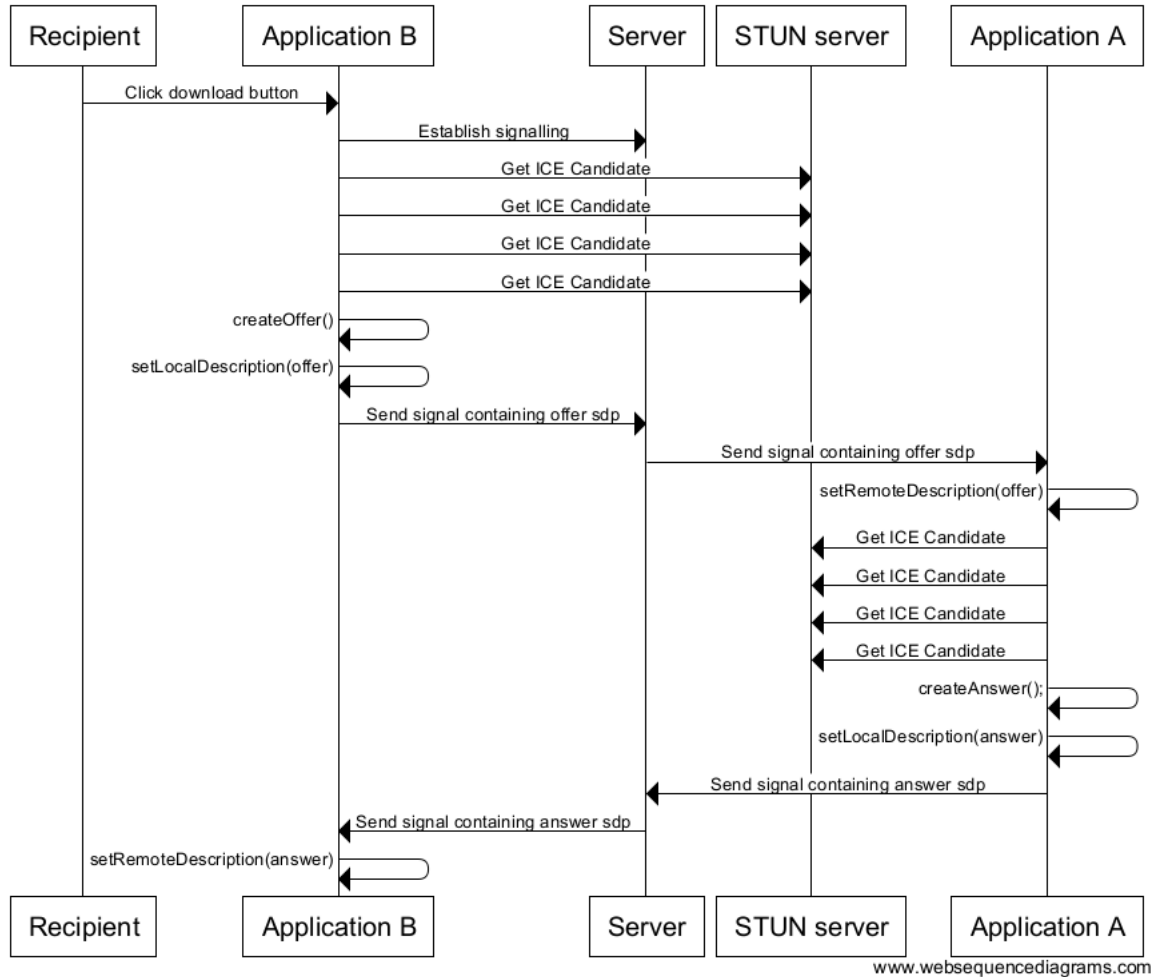


Figure 5.5: File sending sequence in Firefox



Once this file has been received, it is then saved to disk by reading the file in as a data URI and then appending an element to the html with this URL as the reference. A mouse event is then used to simulate the click of this element which triggers the file to download.

5.2.3 Streaming media via peer connection

5.2.3.1 Audio

In order to stream Audio via WebRTC, a media stream is added to the peer connection by the uploader once the offer has been received from the file recipient. Once the answer sdp containing the media parameters for this stream has been sent back and the peer connection is established, an event listener on the recipient application listens for the event signalling the addition of this stream and uses the HTML5 Audio API to create a new audio tag which is appended to the html. The source attribute of this tag is set to the incoming stream and the audio player is set to play automatically. It is important to note that the stream actually starts to play when it is created by the uploader as it is a "live stream" and if there is any latency issues between the two clients, the recipient may only hear part of the incoming stream.

5.2.3.2 Video

I originally planned on also adding video streaming to the application. However, when I looked into this, the part of the MediaStream processing API drafted by W3C that would capture video as a stream has yet to be

implemented by any browsers. Similar to how audio is captured, The `captureStreamUntilEnded()` function would return a `MediaStream` containing both the audio and video tracks of a file which could then be passed to the peer connection and played by a HTML5 video element on the recipient's application.

5.2.4 One-to-many peer connections

Switching to the Node.js implementation of the server allowed me to implement one-to-many peer connections with ease. To do this, the uploader instantiates new peer connections and adds them to an array which are then used to communicate with the recipients which hold one peer connection. Each message sent via the signalling server contains the `socketID` of the user it is from and the user it is destined towards, which is then extracted by the server and used to send messages to only them, this way no socket information can be exposed to anyone except for the user it belongs to.

One of the big disadvantages of this is the potential amount of load on the uploader as they now have to maintain and search through an array of peer connections and as this gets larger, the larger the load. To manage this, the recipient sends a message to the uploader signifying to close the connection and remove it from the array as soon as the recipient has downloaded the file. In the future, I also hope to add this functionality for when a `MediaStream` ends but currently the `MediaStream` API in Firefox has no way of establishing when a stream has finished. The better way of achieving this would be through using a many-to-many network of peer connections and setting a limit to the amount of peers that can be downloading or streaming from an uploader so that when they reach this limit, the load is offloaded to another node that has already downloaded the file. When the whole pools of uploaders becomes saturated with peers, the rest of the peers are added to a FIFO queue and wait for a peer with the file to become free.

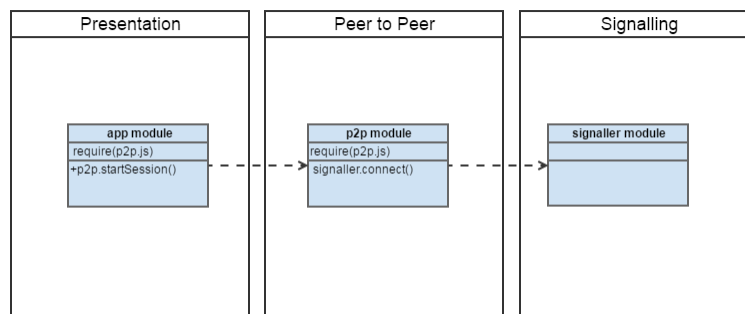
5.2.5 GetStats Library

5.3 Application

5.3.1 Separation of Concerns

As JavaScript can easily become messy, I separated each layer of JavaScript into individual modules by their responsibilities. These layers consisted of the presentation code that had the responsibility of listening to and manipulating the document object model, the peer-to-peer network code that worked with WebRTC to established the peer connections and the signalling code that established the socket connection. By separating these, the code become modular and I can change parts of the code and know that it won't affect how the other modules work. This left the application with a relatively simple architecture.

Figure 5.6: Module Architecture



5.3.2 User Interface

5.3.2.1 Experimenting with JavaScript Frameworks

5.3.2.2 Application States

Chapter 6

Outcomes

6.1 Data

6.2 Discussion

Chapter 7

Review & Reflection

7.1 Other Limitations & Improvements

7.1.1 Testing

7.1.2 Authentication Encryption

7.1.3 Cross-platform Compatibility

7.1.4 HATEOAS

7.2 Methodology

7.2.1 Kanban

7.3 Technologies

7.3.1 JavaScript build tools

7.3.2 Development Environments

7.3.3 Git

7.3.4 Amazon Web Instances

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