JAVASCRIPT PERSISTENCE OBJECTS WITH ADAPTIVE SYNCHRONIZATION TIMING

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Sri Lanka

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Thesis submitted in partial fulfillment of the requirements for the Degree of MSc in Computer Science specializing in Software Architecture

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DECLARATION

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Signature of the supervisor: ……. Date: …….

Name: Dr. Shehan Perera

ABSTRACT

Traditionally, web applications were limited to server generated, dynamic HTML content. With the advancements of web technologies such as HTML5, AJAX and JavaScript Engines, web browsers evolved into application platforms. These have changed the traditional web application architectures, enabling significant part of the web application, runs inside the web browser. Most widely accepted architecture for these web applications uses JavaScript frameworks, that runs inside the web browser, which communicates using the HTTP protocol with RESTful web services, to persist the application state.

There are specialized RESTful web services offered by cloud providers, which are directly capable of persisting objects sent by the web applications. These services provide high scalability, durability and availability of the objects. However, above capabilities comes with a cost, where partial updates of these objects are not possible. To persist dynamically changing objects requires an entire object to be sent to the persistence web service for each modification. When the frequency of dynamically changing object becomes higher, it increases the object persistence round trip time, due to network latency, congestion and persistence web service throttling. Longer response time for persisting objects may cause lower satisfaction and poor productivity among web application users.

This problem can be solved by persisting only the last modification of the object, within a time window. However, having a fix time window, also increases the persistence round trip time for non-frequent modifications.

The aim of this research is to implement a JavaScript framework, which is capable of providing a dynamic persistence time window, to reduce unexpected object persistence round time for frequently changing objects by reducing the network congestion and object persistence web service usage, enhancing overall web application user satisfaction.

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ABBRIVATIONS

API	Application Programming Interface
AJAX	Asynchronous JavaScript and XML
BOM	Browser Object Model
CSS	Cascading Style Sheets
DOM	Document Object Model
ECMA	European Computer Manufacturers Association
HTTP	Hypertext Transfer Protocol
HTML	Hypertext Markup Language
JSON	JavaScript Object Notation
REST	Representational State Transfer
SQL	Structured Query Language
WORA	Write Once Run Anywhere
WORE	Write Once Run Everywhere
W3C	World Wide Web Consortium
GPRS	General Packet Radio Service

CHAPTER 1

INTRODUCTION

Traditionally, web applications were limited to server generated, dynamic HTML content. User interactions with these applications were primitive and allowed to navigate through hyperlinks and filling forms. Additional capabilities such as video streaming were provided by web browser capability extension technologies such as Flash, Java Applets & Silverlight. With the advancements of web technologies such as HTML5, AJAX and Powerful JavaScript Engines, web browsers became much capable of providing rich user interactions. This made web browsers become application platforms [1], that allows to provide capabilities on par with desktop applications. With the wide adoption of W3C standards, by web browser vendors, differences between web browser platforms were minimized. This has largely contributed to the tremendous growth of web applications during the recent few years.

These have changed the traditional web application architectures, enabling significant part of the web application, runs inside the web browser written using JavaScript, CSS & HTML5. With the growing complexity of rich client applications, specialized engineering skills were required, utilizing software engineering patterns and principles to keep the complexities to minimal. Also, reusing code from libraries and frameworks to aid the development process became a norm.

Most widely accepted architecture for these web applications uses web components developed with JavaScript using JavaScript Frameworks like Angular & React which runs inside the browser. These web applications, mainly communicate using the HTTP protocol with RESTful web services, to persist the application state. Apart from that, for very specific use cases such as real-time chat, web sockets are also being used. However, using web sockets has its own limits and still in its early adoption stages.

More specifically for object persistence, there are specialized RESTful web services offered by cloud providers which can directly communicate with the client part of the web applications runs inside the browser. These services provide high scalability, durability and availability of the objects [2] [3]. However, above capabilities comes with a cost, where partial updates of these objects are not possible. To persist dynamically changing objects requires an entire object to be sent to the persistence web service for each modification. When the frequency of dynamically changing object becomes higher, it increases the object persistence round trip time, due to network latency, congestion and persistence web service throttling [4]. Longer response time for persisting objects may cause lower satisfaction and poor productivity among web application users. This problem can be solved by persisting only the last modification of the object, within a time window. This reduces the network congestion and also reduces the usage of persistence web service for higher frequency modifications, but, having a fix time window, also increases the persistence round trip time for non-frequent modifications and increasing the staleness of modified objects. However, this creates challenges for web developers to additionally include a dynamic time window to improve persistence round trip time. In addition, object size, persistence frequency and platform differences and network performance are difficult to predict.

The aim of this research is to implement a JavaScript Framework, which is capable of providing a dynamic persistence time window, to reduce unexpected object persistence round trip time for frequently changing objects by reducing the network congestion and object persistence web service usage, enhancing overall web application user satisfaction.

The remaining parts of the document in structured as follows. Chapter 2 contains the literature review, which covers the theoretical aspects of the evolution of web applications, development, caching, data persistence mechanisms and related work done in this area. Chapter 3 contains the methodology and the architecture of the system developed. Finally, Chapter 4 contains the results and the conclusions drawn from this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Evolution of web and mobile application paradigms

Over the past few years World Wide Web has grown immensely with boundless technology innovations. Initially, it all started with static web pages that only had the simply formatted content and links to other pages. With the rise of user expectations, serving more dynamic content was needed, which lead to the innovation of web server dynamically generated pages, giving birth to real web application engineering paradigm. Overtime dynamic web applications began to get popular, but had its inherited inefficiencies of limited user interactions, delayed loading web pages and delayed response to user actions. Although server performance is improved by caching dynamic data [5] [6] it partially solved the issue. This was due to the limitation of having rich user interactions, where most of the user action required to interact with the web server over the internet with inherent latencies. With the advancement of web browsers and web technologies, modern web applications started to use the web browser as an application platform where a significant part of the application logic executes inside the browser. JavaScript adds dynamism solving some of the inherent inefficiencies with traditional web applications, providing comparable user experience with desktop applications.

With the introduction of fast and efficient JavaScript engines, web browser containers began to be available on smart phone devices, which can run apps developed using web technologies like HTML5, JavaScript and CSS. This has given birth to a new paradigm called hybrid mobile application development. All together these innovations revolutionized the web application development landscape [7], to build web applications that run on a range of devices in different forms. Figure 1 shows a summary of different mobile application types.

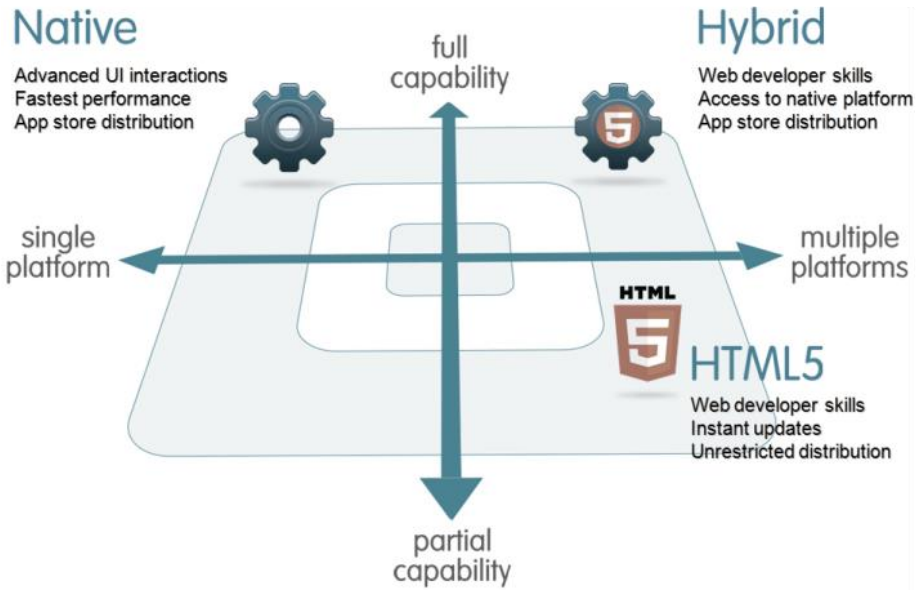

Figure 1: Native, HTML5 and Hybrid mobile application types

Source: http://svitla.com/wp-content/uploads/2013/02/Native_html5_hybrid.png

2.2 Web browser as an application platform

Over the past few years, web browsers had inherent shortcomings. These shortcomings, limited the development of rich web applications for a long period of time.

2.2.1 Web browser performance

Until recently when high performance JavaScript virtual machines were built, native functionality provided by web browsers were pretty slow especially when it comes to computationally intensive applications. The limitation of being single threaded increased the problem. Most of these challenges are now being addressed by the introduction of high performing JavaScript engines such as Google's V8 and the implementation of multithread support for JavaScript included in the HTML5 specification.

2.2.2 User interactions with web browsers

Until very recently web browsers had a very rigid user interaction model with a very primitive set of features. They lacked the desktop like rich user interactions, such as drag and drop, canvas rendering, printing, asynchronous communication & etc. Today almost all the web browsers support these features.

2.2.3 Network and security in web browsers

Most of the issues related to security [8], originated from the document based “One size fits all” browser security model. Decisions on security, mainly focused on the origin of web server, but not by the specific need or functionality of the web application, since these applications run on the sandbox environment with limited access to host machine that the web browser is running in. Now most of these challenges are getting revolutionized since the browsers provide more capabilities to use host machine resources (E.g. File access) and deploying different access control mechanisms.

Apart from these challenges, past web browsers required to reload the pages fully for each request. Now web applications not only capable of asynchronously communicating with the web server, but also communicating in real-time using web sockets.

2.2.4 Web browser compatibility and interoperability

Over the past few years, web browser compatibility was a major challenge. Although web applications are written, "Write once, run anywhere" (WORA), or sometimes write once, run everywhere (WORE) it didn’t work that way in different browsers. Most of the time, rich web applications failed to operate in certain browsers due to the differences in the Browser Object Model (BOM), Document Object Model (DOM) and rendered in unintended compositions and colors due to CSS rendering differences. This has given birth to libraries such as jQuery to be really popular to provide a uniform interface in manipulating. With the wide adoption of W3C standards, by web browser vendors, differences between web browser platforms were minimized.

2.2.5 Web application development and testing

The learning curve from statically typed languages to dynamically typed languages has been a challenge for web developers. Writing complex JavaScript was a difficult task and became challenging in applying software development methodologies due to the fundamental coding style differences like asynchronous, event driven using higher order functions. Debugging these applications also became a challenge during the past where inline code debugging was not available. Now these challenges are getting minimized with modern web browsers having embedded development, debugging and testing tools. Code and pattern reuse with libraries and frameworks also helped to rapidly develop JavaScript heavy web applications.

2.2.6 Web application deployment

One of the main strengths of Web applications is given by the inherent ability of instant deployment. This has revolutionized the software deployment landscape, allowing up to date software to be available instantly to the users with minimal distribution overhead. More recently, with the introduction of HTML5 App Cache, web application distribution has gone an extra mile in supporting the instant distribution of the updated web application to available offline in web browser clients.

2.3 Data driven web applications

With the advancement of web browsers, shift from server side to client side functionality became more apparent. This made the possibility for web applications to implement data handling in the browser, thus providing well needed features to support as an application platform. Client side data handling in web browsers involved in modifying data in the memory, mainly in the form of JavaScript Objects as well as persisting them in client side

storage by serializing the data or directly storing the object depends on the storage of choice.

These web applications are capable of using the web browser storage or in memory storage, as well as distant storage to persist the data for long term storage and sharing. Figure 2 shows a basic overview of web and hybrid mobile application data communication model.

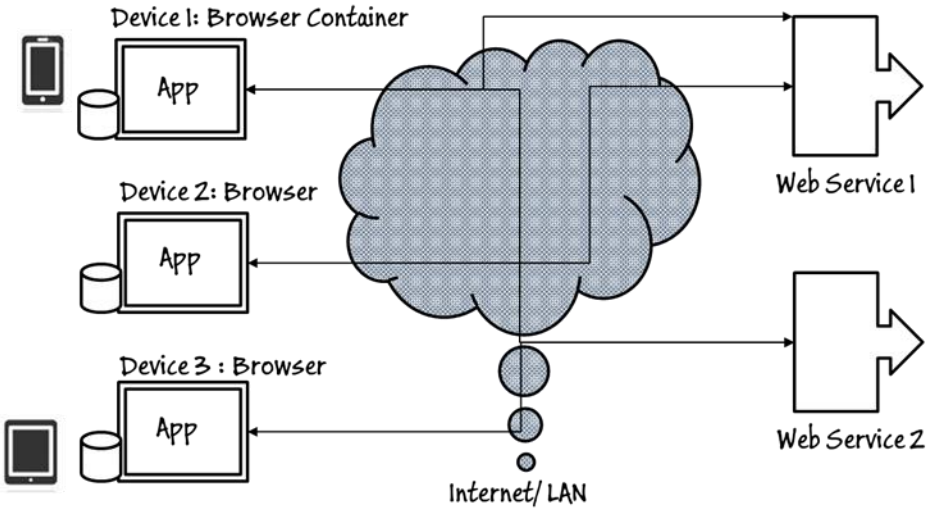

Figure 2: Web and hybrid mobile applications

2.4 Storage in web applications context

Web applications are capable of storing, data on the web servers for long term persistence and on client-side storage for temporal persistence. Conventional interaction model with server, has the following disadvantage [9].

1. Need of network connection availability for data persistence
2. Increased network congestion
3. Increase server load

This leads to the reduced performance. The conventional client-server interaction model is shown in Figure 3.

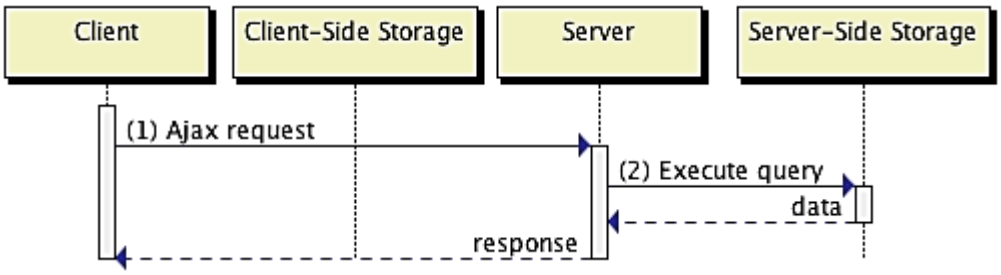

Figure 3: Client-server Interaction Model

Source: Figure 1 [9]

Usage of client-side storage or memory can minimize the above disadvantages illustrated using the following interaction model.

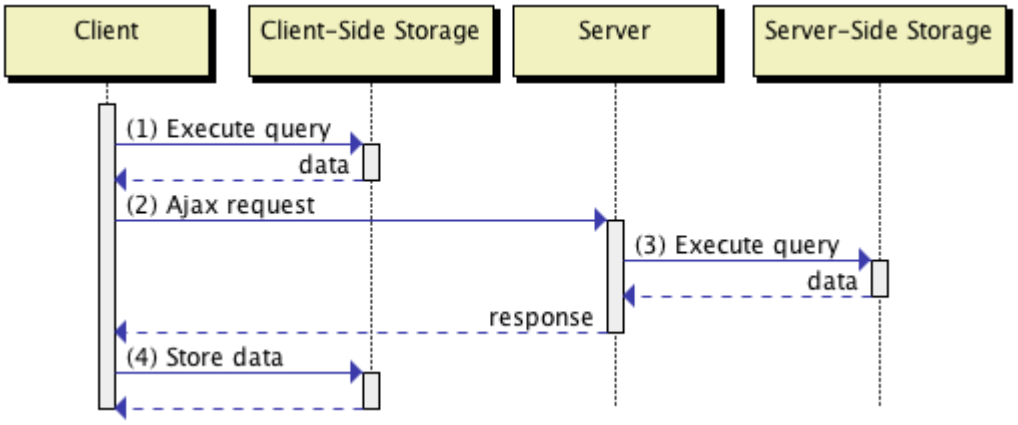

Figure 4: Client-server interaction model utilizing client-side storage or memory

Source: Figure 2 [9]

However, this introduces another challenge of data staleness, where client side is not having the most up-to-date data.

2.5 Abstracting storage in web applications

2.5.1 Separating web applications from user data storage with BSTORE

BSTORE is a framework that allows web developers to separate the application logic from its data storage providing a unified API to access data. It is designed to achieve

independence between applications and storage provides allowing almost any application, avoiding the need for reserving any special functionality for the user.

Figure 5 shows an overview of the BSTORE architecture where component in the browser corresponds to a separate window whose web page contains JavaScript code that communicates with BSTORE. All requests are sent from each web page to the BSTORE file system are mediated by the FS manager.

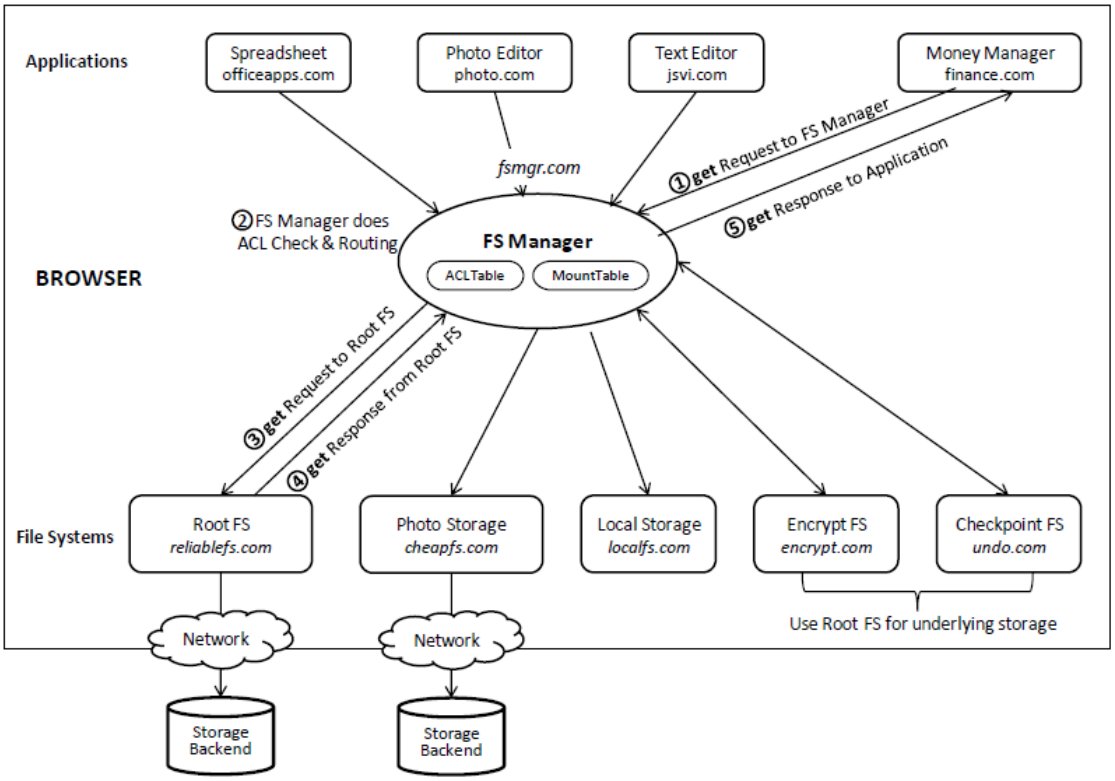

Figure 5: BSTORE architecture

Source: Figure 1 [10]

BSTORE client-side components are implemented using JavaScript targeting FireFox and Google Chrome web browsers. The specialty of BSTORE is that, each component runs on separate browser window loaded from a separate domain which also becomes a drawback when it comes to commercial applications where BSTORE to work requires multiple

windows to be open at the same time. Communication between each of these browser windows are done using "postMessage" command. BSTORE communicates with the server storage system through AJAX and authenticated using, plain user credentials.

2.6 Utilizing client-side storage for web application performance

2.6.1 Sync Kit

Sync Kit [11] is a client/server toolkit for improving the performance of data intensive web applications. Sync Kit offers a mechanism to offload some of the data from a web server to (Google) Gears [12] on the client side, requiring the installation of the Gears plug-in in order to work. In future Gears could be, however, replaced with a W3C-specified client-side storage mechanism to get rid of the dependencies. On the server side, Sync Kit requires a specially designed web server that handles Sync Kit requests. In their case, Sync Kit was implemented as a collection of scripts for the Django10 web framework. The focus of Sync Kit is to use Gears to store (cache) segment of web pages called web page templates on the client side. These templates include a JavaScript library and data endpoint definitions to access dynamic contents residing on the server. Data endpoints, on the other hand, cache database objects to Gears and keep the cached data consistent with the server database. When a browser loads a web page for the first time, the template is returned as a response from the Sync Kit aware server and stored in the client-side storage. Then, new data is requested via the template's data endpoints. Finally, the retrieved data is added to the template, cached on the client-side storage, and the result is displayed to the user as shown in Figure 6 and Figure 7.

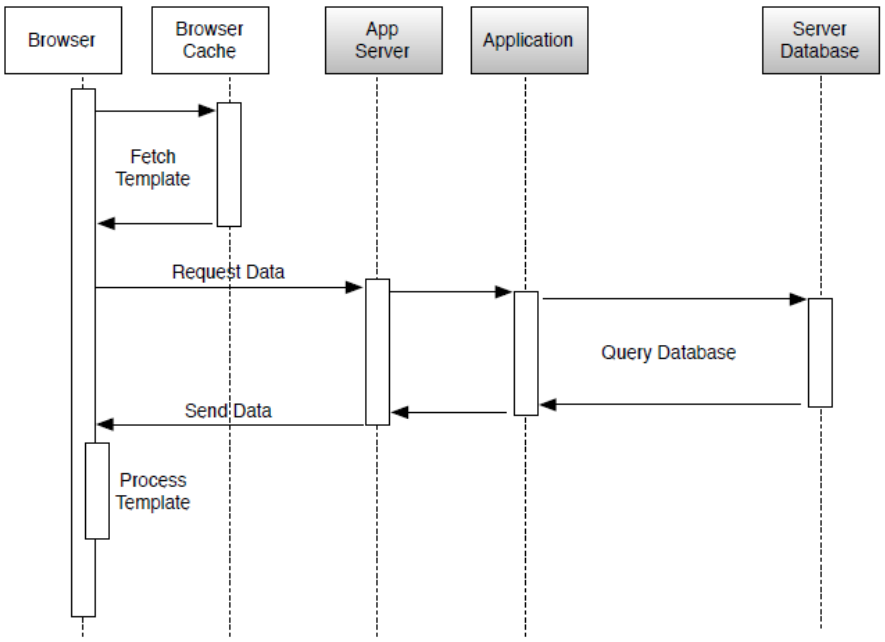

Figure 6: Template caching: Template rendering is on client

Source: (b) [11]

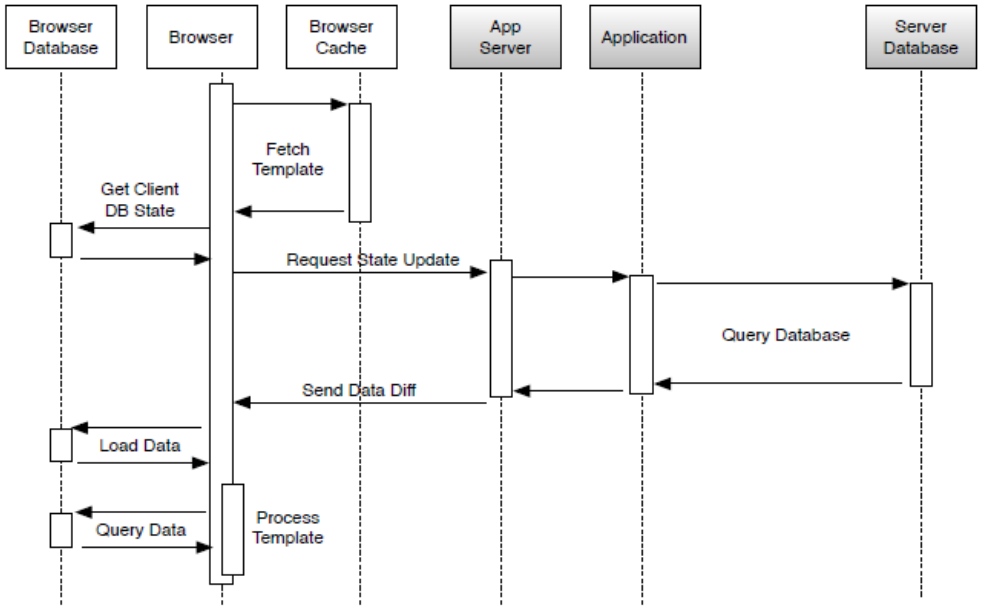

Figure 7: Sync Kit: Template rendering and database accesses

Source: (C) [11]

According to the research [11], their solution given by Sync Kit reduces server load by a factor of four and data transfer up to 5% compared to the traditional approach, when cache hit rates are high.

One of the main challenges of Sync Kit is that it requires Sync Kit aware web server implementation in server side that limits its usage in practical web application developments where more of these applications are built on top of third party APIs and services. Apart from that, it restricts the client-side implementation to be based on Sync Kit provided client-side template mechanism where better mechanisms are coming out more frequently suiting different JavaScript libraries and framework stacks.

2.6.2 Silo

Silo [18] is a framework that allows to create fast-loading web applications. It uses JavaScript and client-side storage based on current web standards, allowing the approach to be working on modern web browsers. On the server side, a Siloaware web server is required. The main purpose of Silo is to use client storage to cache website's JavaScript and CSS chunks (2 KB in size) on the client-side so that it is not needed to be requested from the server in each page load.

When a browser requests for a specific web page, the server returns a modified version of the web page containing a small JavaScript file with a list of required chunk ids and logic to fetch missing chuck IDs. Then the loaded JavaScript file logic checks the client-side storage for available chunks, and informs the server of the missing chunks using their ids where the server replies with the raw data for the missing chunks. Finally, the web page is reconstructed in its original form on the client using the JavaScript logic. Apart from that, for the latter HTTP request, the round trip can be completely eliminated by utilizing HTTP cookies in the initial HTTP request for sending the already available chunk ids. The Silo was evaluated with multiple real-world websites, such as CNN, Twitter, and Wikipedia.

Based on their experiments, it was proven that Silo can reduce web page load time by 20-80% for web pages with large amounts of JavaScript and CSS.

With the latest HTML5 standards, almost all the functionality provided by Silo can be achieved using App Cache and Client-side storages but stored separately in the browser. But the challenge addressed by providing a unified way of loading web page content (Both content and data in forms of chunks) provides several other challenges when it comes to practical web application development, making things really hard to test and debug.

2.7 Client-server data synchronization and persistence

2.7.1 Data synchronization patterns in mobile application design

Many mobile applications are data centric [13] . This is same with modern web applications. This research [13] describes common concerns related to data synchronization as a collection of patterns, grouped by the problems they address. These patterns are based on examining open source applications, inspecting platforms and frameworks of mobile systems and examining experiences developing mobile applications taking input from different experience developers.

The paper states that it is not possible to find one-size-fits-all solution for data synchronization which provides the need of configuring a data synchronization framework to suit different domains and environments. This becomes really obvious when considering indirect factors like power usage, especially when it comes to mobile devices, and efficient synchronization mechanism [14] needs to be selected based on various criteria.

As described in the paper these collections of patterns can be further classified into the following 3 collections of patterns.

1) Data synchronization mechanism patterns
2) Data storage and availability patterns

3) Data transfer patterns

2.7.1.1 Data synchronization mechanism patterns

These collections of patterns addresses the question: “when should an application synchronize data between a device and a remote system (such as a cloud server)?” [13]. These patterns can be further classified into two types based on the mechanism that the data transfer occurs.

- Asynchronous data synchronization:
  Where data synchronization happens asynchronously without blocking the user interface.
- Synchronous data synchronization:
  Manage a data synchronization event synchronously; blocking the user interface while it occurs.

2.7.1.2 Data storage and availability patterns

These collections of patterns address the questions: “how much data should be stored?” and “how much data should be available without further transfer of data?” [13]. These considerations often depend on the limitations of mobile platforms which is similarly applicable to web browser platforms. Based on the amount of data stored locally, these collections of patterns can be further classified into the following types.

- Partial storage:
  Synchronize and store data only as needed to optimize network bandwidth and storage space usage.
- Complete storage:
  Synchronize and store data before it is needed so the application has better response or loading time.

2.7.1.3 Data transfer patterns

These collections of patterns addresses address the problem of transfer quantity in set reconciliation: “how can we synchronize between sets of data such that the amount of data transmitted is minimized?” [13]. Selection of the transfer quantity needs to be carefully selected based on the application domain to optimize the network bandwidth. Further classification of data transfer patterns is shown below.

- Full transfer:

  On a synchronization event, the entire dataset is transferred between the mobile device and the remote system.
- Timestamp transfer:

  On a synchronization event, only the parts of the dataset changed since the last synchronization are transferred between the mobile device and the remote system using a last-changed timestamp.
- Mathematical transfer:

  On a synchronization event, only the parts of the dataset changed since the last synchronization are transferred between the mobile device and the remote system using a mathematical method.

2.7.2 Efficient synchronization of replicated data in distributed Systems (nSync)

This research present nsync [15], a tool for synchronizing large replicated data sets in distributed systems. Although these concerns are not directly applicable for web applications, the strategy of optimizing the synchronization plans provides a sound approach in optimally synchronizing batches of replicated data when multiple servers are present [16]. When it comes to data synchronization, nsync approach computes nearly optimal synchronization plans before actual synchronization happens to minimize the amount of data needs to be transferred using a hierarchy of gossip algorithms that take the network topology into account.

Figure 8, illustrates the capability of nsync when it comes to synchronizing multiple nodes. In native approach without nsync, each single connection would trigger an independent disk access, provoking many disk head movements and therefore resulting in a slow data transfer rate. To avoid this, nsync approach uses only node to node (n2n) syncs, where each node participates in at most one n2n sync at a time.

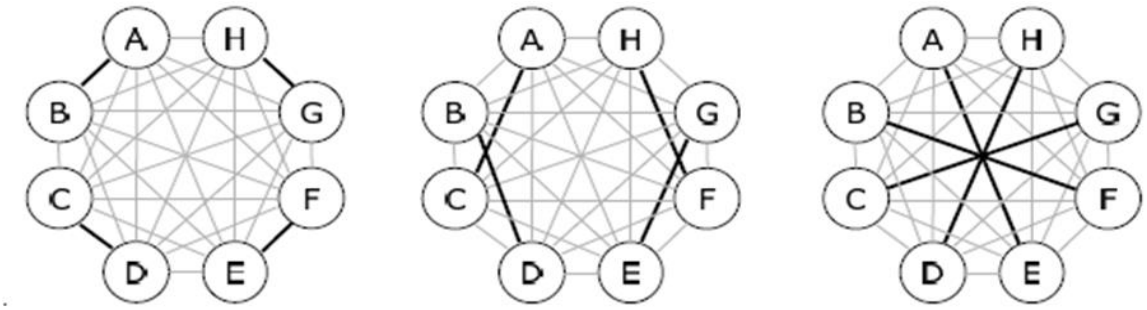

Figure 8: Three rounds of n2n syncs can synchronize eight nodes
Source: Figure. 1 [15]

2.7.3 Automated object persistence for JavaScript

Automated persistence of JavaScript Objects [17] provides a transparent mechanism on persisting structured objects. Still with automated persistence, web application developers, need to determine how and when to save data using the heap-allocated JavaScript objects to local browser storage balancing several tradeoffs. If the changes are saved quite often, it causes degradation of performance and the single threaded nature of JavaScript (At the time being research was conducted) causes to freeze the browser when saving single large batch of changes. To deal with this problem, they have investigated the use of persistence by reachability [18] for JavaScript. This approach divides the JavaScript object heap into transient and persistent sub-graphs allowing the framework to manage persistence-related tasks periodically. This way the framework manages between transient and persistent objects not immediately persisting the objects each time it gets updated.

Secondly, to synchronize data between client-storage to servers, they have investigated and developed an application framework for automated persistence at an individual object granularity, allowing the browser to send updates of the data for individual objects which maps directly to the object model created by the application developer. When there is a conflict happens, the framework triggers a conflict resolution callback where the developer needs to write a semantically relevant resolution strategy.

The automated object persistence framework uses special functions called “accessors” in JavaScript to identify whether an object attribute is updated. These “accessors” are called transparently when an object property is read or written. In this framework, when a write operation happened, triggering the “accessor”, it records that the object as mutated and stores the written value so it can be returned by the read “accessor”. Since JavaScript is a dynamic language, a scheduled process runs to identify whether new properties are added to the JavaScript object, carefully selecting the schedule intervals to avoid overhead.

As shown in the architecture diagram in Figure 9, “accessors” act as a read barrier to alert the framework when a persistent object has mutated. These Mutations including both “accessors” and the dynamic property addition, maintenance task, causes objects to be added to the live object set that is constantly updated by the application and have their state stored in local storage. This is to assure that the objects are stored safely in the browser if the browser crashed before persisting the objects. Garbage collection removes dead objects from local storage. Finally, mutations are sent to a server during remote synchronization.

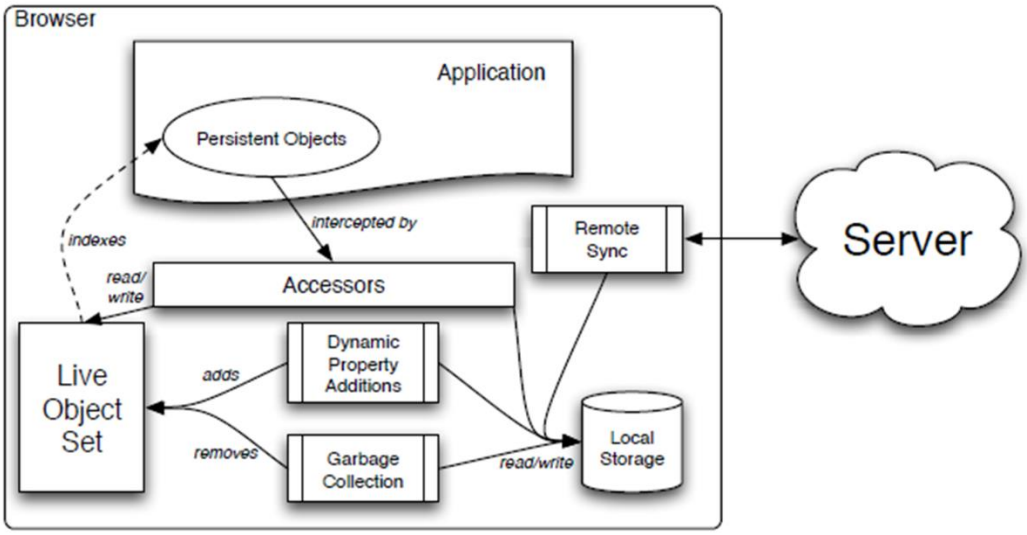

Figure 9: Architecture diagram of automated object persistence mechanism
Source: Figure 1 [17]

This paper provides a sound approach, in providing semi-transparent object persistence mechanisms using a framework. Some of the key decisions made based on the single thread nature of JavaScript are no longer valid since now JavaScript supports multiple threads with web browser technology advancements.

2.8 Response time impact for web application user experience

In modern web applications user satisfaction heavily depends on application response time. With the advancements of web browser performance, network speeds, one might not expect to have to deal with performance issues in web applications such as slower response time. But these issues remain a very real concern today.

According to the research System Response Time and User Satisfaction [19], system response time has a related effect for user satisfaction. According to the study Figure 10 shows that the user satisfaction has a correlation with response time where it decreases as

response time increases. It also showed that for web applications, it appears to be a level of intolerance in the 12-second response range.

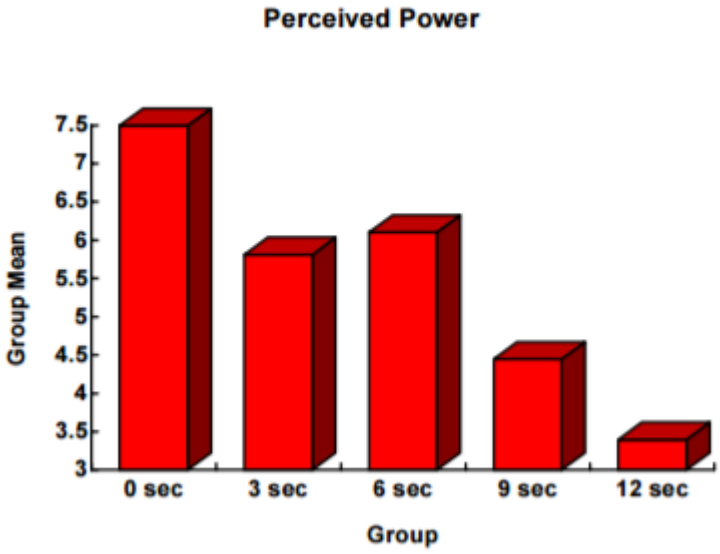

Figure 10: Perceived power construct

Source: Figure 4 [19]

CHAPTER 3

METHODOLOGY

The adaptive JavaScript object persistence framework consists of multiple components. The persistence algorithm in the framework intervenes the JavaScript object persisting operation and adjust the object persistence request initiating time, for high frequency actions. After the automated experiment is carried out, window size and other results of the experiments are saved for future analysis and prediction.

3.1 JavaScript persistence objects

In web applications object representation can take multiple formats. Most popular forms of JavaScript objects created with JavaScript Object Literal Notation (JSON). These objects consist of attributes and collections in the form of primitives and arrays. An example JSON object is shown in the Figure 11.


```
{
  "todos": [
    {
      "title": "Item 1",
      "completed": false
    },
    {
      "title": "Item 2",
      "completed": false
    },
    {
      "title": "Item 3",
      "completed": false
    },
    {
      "title": "Item 4",
      "completed": false
    }
  ],
  "request_id": "8ae873a4-5634-75d6-3bf8-ed93bf4572d1"
}
```


Figure 11: JavaScript Object Notation

Apart from these JavaScript Object Notation, JavaScript Engines in web browsers also allows to upload binary objects which could be directly sent to web services.

3.2 Object persistence web Services

Object persistence web services are set of web services which allows to store objects sent over HTTP protocol with a payload of JSON or blob objects. These services internally handle the persistence complexities of the objects and also provides other capabilities such as updating, deleting objects.

3.3 Factors and their ranges

JavaScript object persistence performance is impacted by various parameters such as

- Object modification & persistence frequency
- Object size
- Network performance (Bandwidth and Latency)
- Platform (Browser/Operating System)
- Web application specific parameters
- Performance of persistence web service

If we take a particular feature of a web application that needs to persist a JavaScript object, it has a size, and user interaction frequency to persist the object within a quantifiable range which allows to model a characteristic of a feature. Optionally, other factors also help to classify the user, such as an authenticated user identity, platform identifying data (browser cookies) which could be used to further increase the predictability of user behavior with respect to persist frequency. Apart from that, most of these factors impact persistence response time, influenced in different levels and it is quite difficult to identify ranges for some of them. For example, web application specific parameters such as web browser, underlying device hardware, operating system and performance of persistence web service, will be different for different web applications and they are also changing over time.

Therefore, an adaptive method is needed to predict the persistence time window for a given feature to optimize the performance for object persistence for high persistence frequencies.

3.4 JavaScript object persistence models

3.4.1 Persistence model: direct persistence

In modern web application, the object changes are persisted in RESTful web services. If we model the modifications and persistence round trip time of the object, it is a series of modifications that happens with time. To store the state of the object on the remote server requires it to trigger a server data persistence AJAX request that takes a round trip time (RTT) to the sever to persist the data remotely and send back the acknowledgement. In the direct persistence model, it immediately persists the object, when the object identifies a change in its attributes. Figure 12 illustrates this model and how these steps taken place.

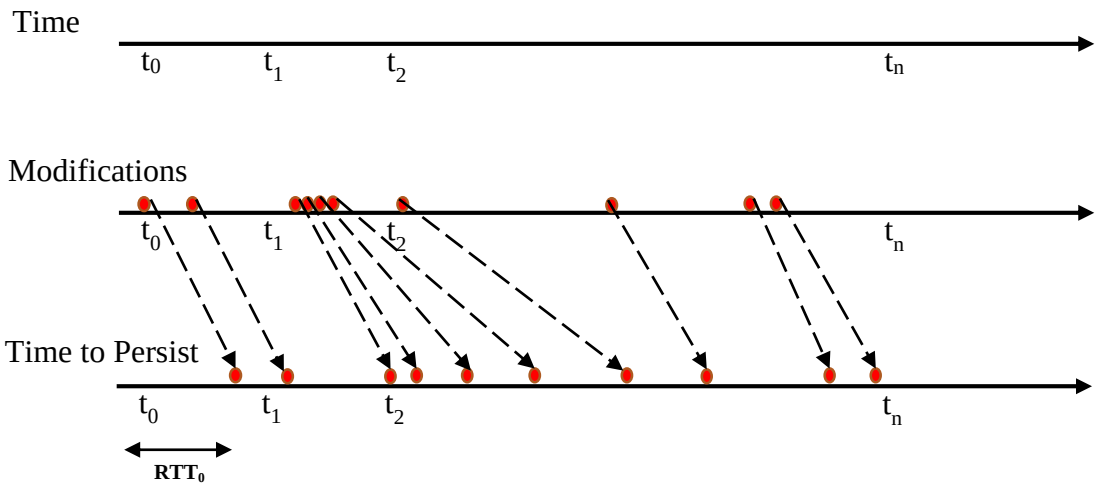

Figure 12: JavaScript persistence illustrated

RTT- Round trip time (Client-Server-Client)

W- Modification time window

3.4.2 Persistence model: dynamic modification window persistence

In the dynamic modification window persistence model, object changes are not directly sent to the server. A time window is calculated and within the window only the last object change is sent for persistence reducing the network congestion and service usage. Figure 13 illustrates this model and how these steps taken place.

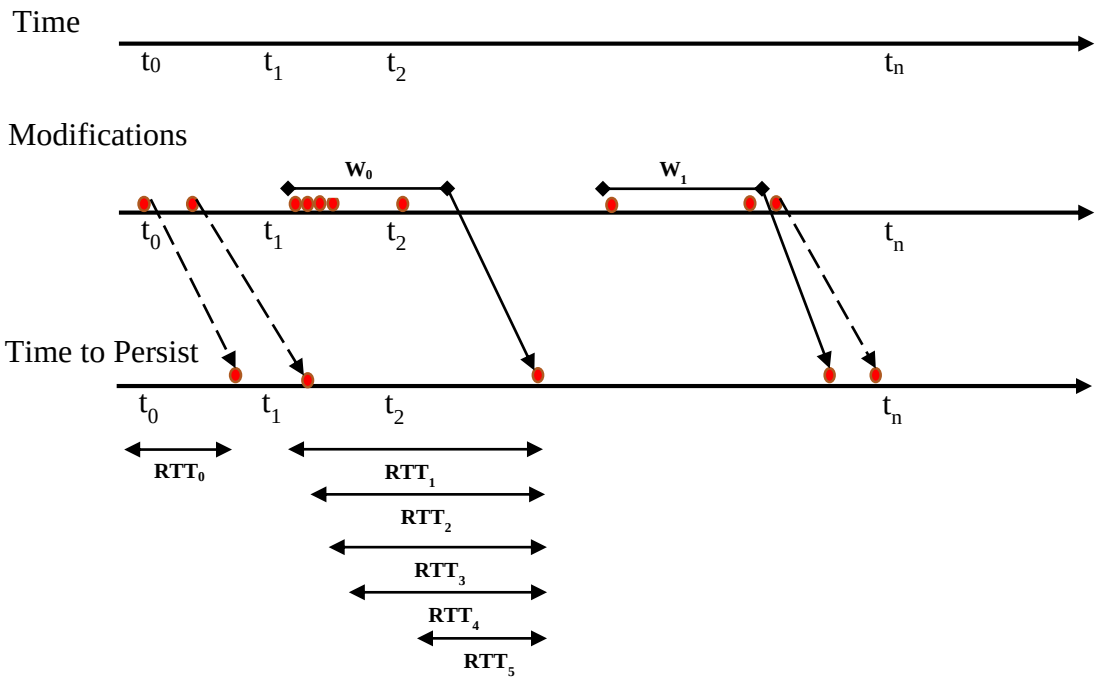

Figure 13: Dynamic modification window persistence

This forms the following equation for round trip time Average (WRTT (m)) taking modification time window into account, to persist an object after **m** requests.

$$\text{Window RTT Average [WRTT (m)]} = \frac{\sum_{x=1}^{x=m} RT(x) + W(x) - ST(x)}{\sum_{x=1}^{x=m} x}$$

Request RTT for request **m,** [RTT (m)] $= RT(x) - ST(x)$

Where:

ST(x) = Start request time, RT(x) = Response received time, W(x) = Modification time window for a request **x**.

3.4.2.1 Predicting next request round trip time

To calculate the dynamic persistence window size for dynamic modification window persistence, polynomial regression is being used to predict the next persistence round trip time. To determine the order of polynomial regression, a higher order is initially selected and equation is calculated as shown below.

$$y = 0x\text{^}10 + 0x\text{^}9 + 0x\text{^}8 + 0x\text{^}7 + 0x\text{^}6 + 0x\text{^}5 + 0x\text{^}4 + -0.12x\text{^}3 + -5.73x\text{^}2 + 765.62x + 943.16$$

It has been found that a polynomial regression with order 3 is sufficient to predict the next request round trip time since the higher order coefficients are equal or close to zero. After retrieval of each response, round trip time is logged and use to predict the next value using polynomial regression.

3.4.2.2 Adjusting dynamic modification window size

W_{size} is calculated as follows after **m** requests

If $RTT_{predicted}(m+1) - RTT(m)) > \Delta RTT_{threshold}$, Then

$W_{size}(m) = W_{size}(previous) + \Delta W_{increment}$

Else

$W_{size}(m) = MAX((W_{size}(previous) - \Delta W_{decrement}), 0)$

End

Where:

Round trip time threshold = $\Delta RTT_{threshold}$, Predicted next request round trip time = $RTT_{predicted}(m+1)$, Modification window threshold = $\Delta W_{threshold}$, Modification window increment = $\Delta W_{increment}$, Modification window decrement = $\Delta W_{decrement}$

Other metrics calculated for future analysis include

Minimum round trip time = RTT_{min}, Maximum round trip time = RTT_{max}

3.4.3 Persistence model: dynamic modification window persistence with initial window size

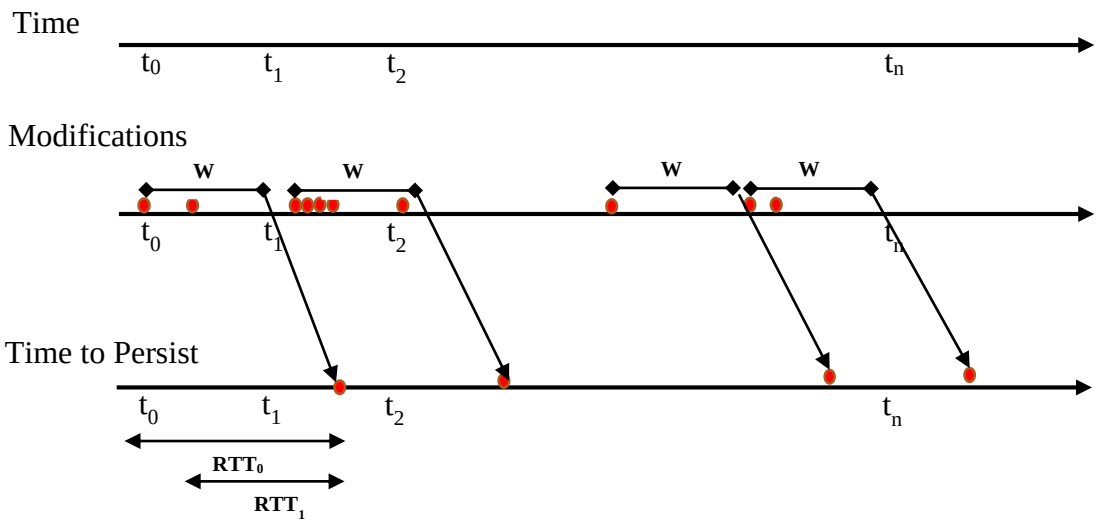

Figure 14: Dynamic modification window persistence with initial window size

In dynamic modification window persistence model, the window size is calculated dynamically to reduce network congestion. However, if high frequency object modifications happen immediately after starting the application, the network congestion and service usage can increase since the dynamic modification window calculation happens after individual responses arrives. In this persistence model, it initializes a suitable modification window at the beginning of the persistence request to avoid high frequency updates happening immediately. To predict the initial persistence window size $W_{initial\ size}$, further research needs to be carried out by using the data from dynamic modification window persistence model experiments.

3.5 Experiment setup

3.5.1 JavaScript object persistence window experiment

Persistence workload is created with JavaScript objects considering JavaScript object size, persistence frequency and network in to consideration. Figure 15 illustrates the experiment setup.

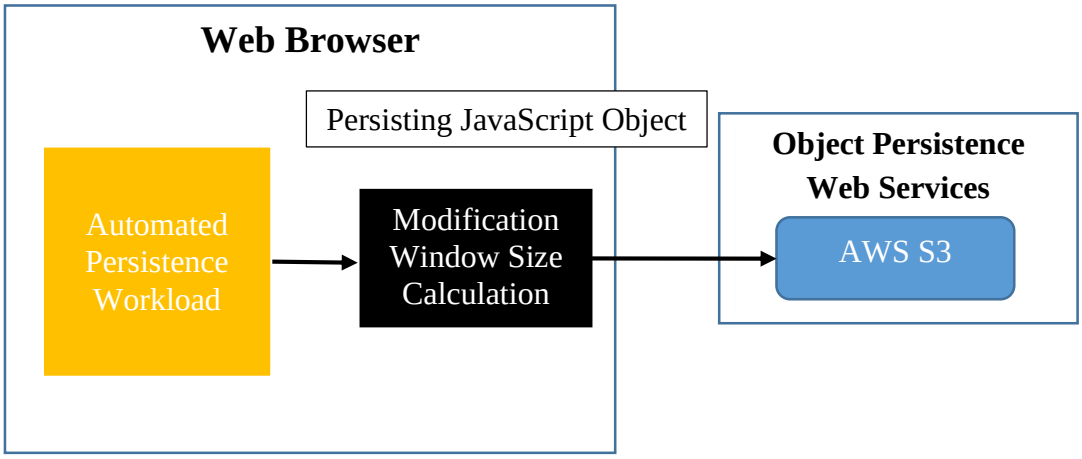

Figure 15: Experiment setup

3.5.2 Predicting next request round trip time

To predict next request round trip time, following function is used where the order of the polynomial regression algorithm is specified. Figure 16, illustrates the logic implemented to predict the next request round trip time.

```
predictNextRTT = function(req) {
    if (REQ.log.length < 3) {
        return req.requestRTT;
    };
    var result, reqLogs = utils.clone(REQ.log);
    reqLogs.push([reqLogs.length, null]);
    result = regression('polynomial', reqLogs, 3);
    return Math.abs(Math.round(_.last(_.last(result.points))));
},
```

Figure 16: Predicting next request round trip time

3.5.3 Changing persistence frequency

JavaScript object modification frequencies are simulated using a JavaScript interval function and using QUnit framework. Figure 17, illustrates the logic implemented to simulate persistence frequencies and object modifications.

```
asyncTest('Experiment with 1KB and 20 requests/second with 100 iterations', function() {
    var iterations = 100,
        uploadLogs;

    var refreshIntervalId = setInterval(function() {
        iterations--;
        reqwin.adaptiveWindow(EXPERIMENT.upload).then(function(logs) {
            uploadLogs = logs;
        })
        if (iterations === 0) {
            clearInterval(refreshIntervalId);
        }
    }, 50);

    expect(1);
    _.delay(function() {
        var logs = formatLogs(uploadLogs);
        ok(true, JSON.stringify(logs));
        start();
    }, 20000);
});
```

Figure 17: Simulating JavaScript persistence frequency

3.5.4 Changing latency, network bandwidth

Throughout the experiment, latency differences are kept to a minimum by using the same geographical distance between the client and the persistence service. Network bandwidth and additional latency are simulated using Google Chrome Developer Tools as shown in Figure 18. Also, many iterations are carried out to reduce the error factor when comparing results.

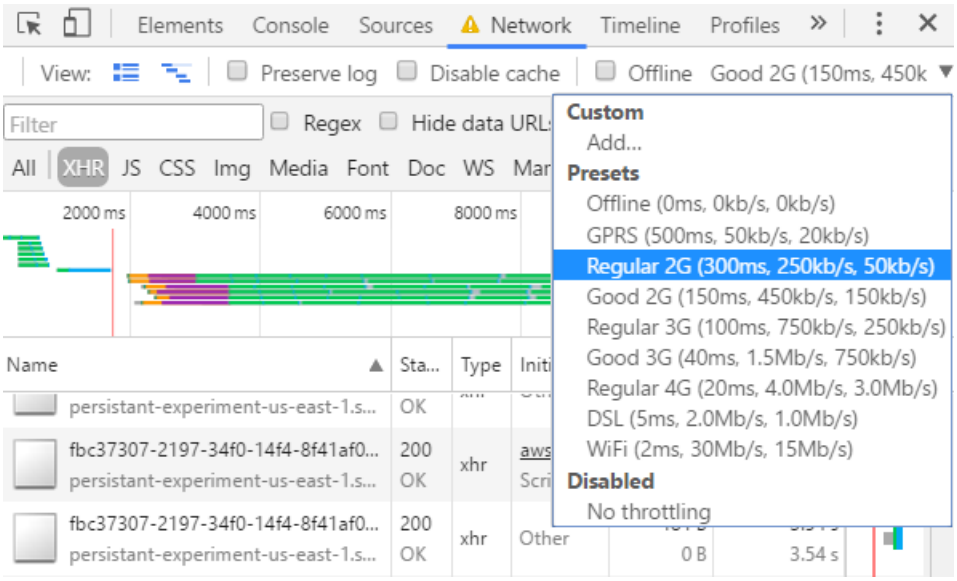

Figure 18: Simulating network bandwidth & latency

3.5.5 Adjusting persistence modification window algorithm parameters

The persistence algorithm works asynchronously adding persistence time window for a provided “Save Callback” function so that, the actual persistence logic is written outside the algorithm itself. This helps to inject various persistence mechanisms reusing the algorithm implemented. For instance, saving on Amazon S3 persistence service is implemented as shown in Figure 19.

```
(function(W, $) {
    W.AP = W.AP || {};
    AWS.config.update(W.AP.AWS_CREDENTIALS);
    var recordsLog = {};

    AP.persist = {
        upload: function(obj) {
            var deferred = Q.defer(),
                s3 = new AWS.S3(),
                params = {
                    Bucket: 'persistant-experiment-us-east-1',
                    Key: obj.request_id,
                    StorageClass: 'REDUCED_REDUNDANCY',
                    Body: JSON.stringify(obj)
                };
            recordsLog[obj.request_id] = W.AP.utils.clone(obj);
            s3.upload(params, function(err, res) {
                deferred.resolve(recordsLog[res.key]);
            });
            return deferred.promise;
        }
    };
})(window, jQuery);
```

Figure 19: Persistence logic in Amazon S3

In the persistence algorithm, there are several parameters we need to adjust to optimize the algorithm for varying scenarios. During these experiments the effect of these parameters are further analyzed and predicting it for various scenarios requires further research using an analytical approach for real web applications, collecting the data of its performance results. Following are the parameters that need to be modified to optimize the algorithm for specific usage.

1. Initial window size
2. Window increment and decrement
3. Round trip time threshold

3.5.6 Implementing dynamic modification window persistence model

Persistence window calculation algorithm has 3 steps. In the first step as shown in Figure 20, algorithm buffers further requests, if they are within the window size. If the window

size is 0, then all the persistence requests are being sent to the server. To send particular versions of the object change to the server, the persistence callback is called, upon its success.

```
adaptiveWindow = function(saveCallback) {
    var deferred = Q.defer(),
        currentRequestAt = utils.timestamp(),
        waitingWindow;
    records.lastRequestedAt = records.lastRequestedAt || utils.timestamp();
    waitingWindow = currentRequestAt - records.lastRequestedAt
    REQ.total++;

    records.window.push({
        request_at: currentRequestAt
    });

    var executeRequest = function() {
        var requestId = utils.guid();
        records.lastRequestedAt = utils.timestamp();
        records.saving[requestId] = utils.clone(records.window);
        records.saving[requestId].request_at = records.lastRequestedAt;
        records.window.length = 0;
        saveCallback(requestId, records.lastRequestedAt).then(function(obj) {
            W.count++;
            var requestRTT = (utils.timestamp() - records.saving[obj.request_id].request_at);
            W.time = W.time + requestRTT;
            records.saving[obj.request_id].forEach(function(record) {
                var result = {
                    requestRTT: requestRTT,
                    serveTime: utils.timestamp() - record.request_at + W.size
                };
                updateVariables(result);
                adjustRequestWindow(result);
            });
            deferred.resolve(LOGS);
        });
    };

    if (!W.size || waitingWindow >= W.size) {
        executeRequest();
    } else if (!records.pendingDelayedExecutions) {
        records.pendingDelayedExecutions = true;
        _.delay(function() {
            records.pendingDelayedExecutions = false;
            executeRequest();
        }, (W.size - waitingWindow));
    }

    return deferred.promise;
};
```

Figure 20: Persistence window buffer and persistence callback

In the second step algorithm re-calculates its statistics as shown in Figure 21 which is used to dynamically calculate the persistence window during the next step.

```
updateVariables = function(record) {
    REQ.served++;
    REQ.time = REQ.time + record.requestRTT;
    REQ.average = Math.round(REQ.time / (REQ.served || 1));
    RTT.average = Math.round(W.time / (W.count || 1));
    RTT.min = (record.requestRTT > RTT.min) && RTT.min ? RTT.min : record.requestRTT;
    RTT.max = (record.requestRTT > RTT.max) ? record.requestRTT : RTT.max;

    var log = utils.clone({
        RTT: RTT,
        W: W,
        REQ: REQ
    });
    log.REQ.windowRTT = record.windowRTT;
    log.REQ.requestRTT = record.requestRTT;
    LOGS.push(log);
},
```

Figure 21: Calculating algorithm statistics

During the third step, it adjusts its window size accordingly using the persistence model, dynamic modification window persistence as shown in Figure 22.

```
adjustRequestWindow = function(req) {
    if (!W.disabled) {
        if (RTT.nextRTT - req.requestRTT > RTT.threshold) {
            W.size = W.size + W.increment;
        } else {
            W.size = W.size - W.decrement;
            W.size = W.size > 0 ? W.size : 0;
        }
    }
},
```

Figure 22: Adjusting persistence window

The first stage of the experiment is carried out without the persistence time window in range of object modification frequencies. In the next stage, different sizes of fixed persistence time windows are added and the result is calculated. At the last stage of the

experiment, dynamic modification time window is added, in between the automated object persistence workload and Amazon S3 web service. Using the automated interval script, workload frequency is simulated and required persistence algorithm parameters are modified accordingly. After simulation completes, a delayed function shows experiment results in QUnit web interface and shown in Figure 23. In addition, the results of the experiments automatically added to an Excel Sheet for further analysis.

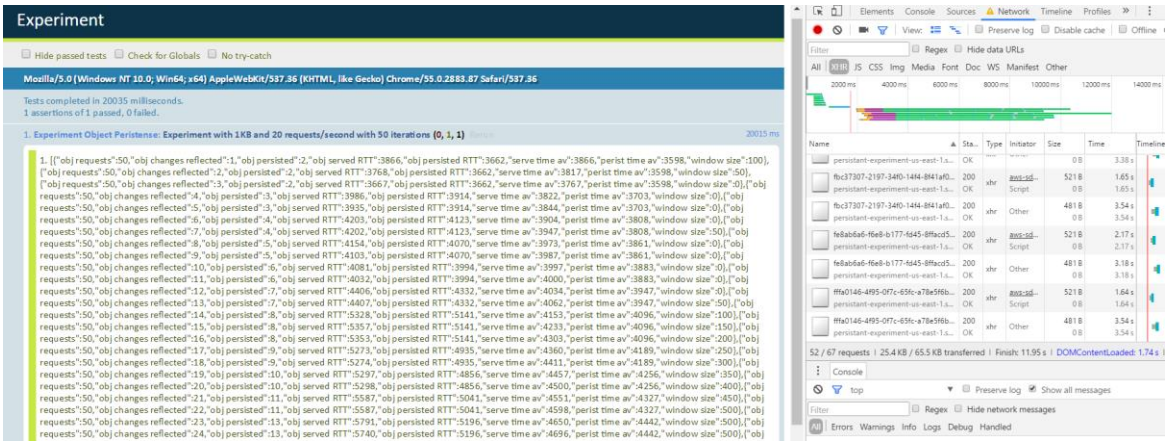

Figure 23: Displaying results using QUnit Framework and Google Chrome inspector

CHAPTER 4

Results & Conclusion

When implementing the adaptive object persistence JavaScript framework, it was required to find a suitable approach to reduce the object persistence round trip time, in high object persistence frequencies. By simulating a web application environment using a web browser client and a persistence web service, as described in the methodology, automated experiments were carried out in 3 stages, modifying different parameters that affect the object persistence round trip time.

1. Without persistence time window (Directly persisting)
2. With fixed persistence time window
3. With dynamic persistence time window

The results obtained from the experiments are analyzed in this chapter and discussions are carried out interpreting the results. At the end of the chapter, it comes to the conclusions of experimental findings. At last, future work is proposed to further expand the research.

4.1 Directly persisting without persistence time window

In the first stage of the experiment, objects are directly persisted. The experiment is carried out by changing the network latency and speed using Google Chrome Developer Tools and object modification frequency. Figure 24 shows, change in persistence round trip time for different object modification frequencies in a simulated GPRS mobile network with 500ms extra latency and 20-50kb/s data transfer speeds using 1KB size object.

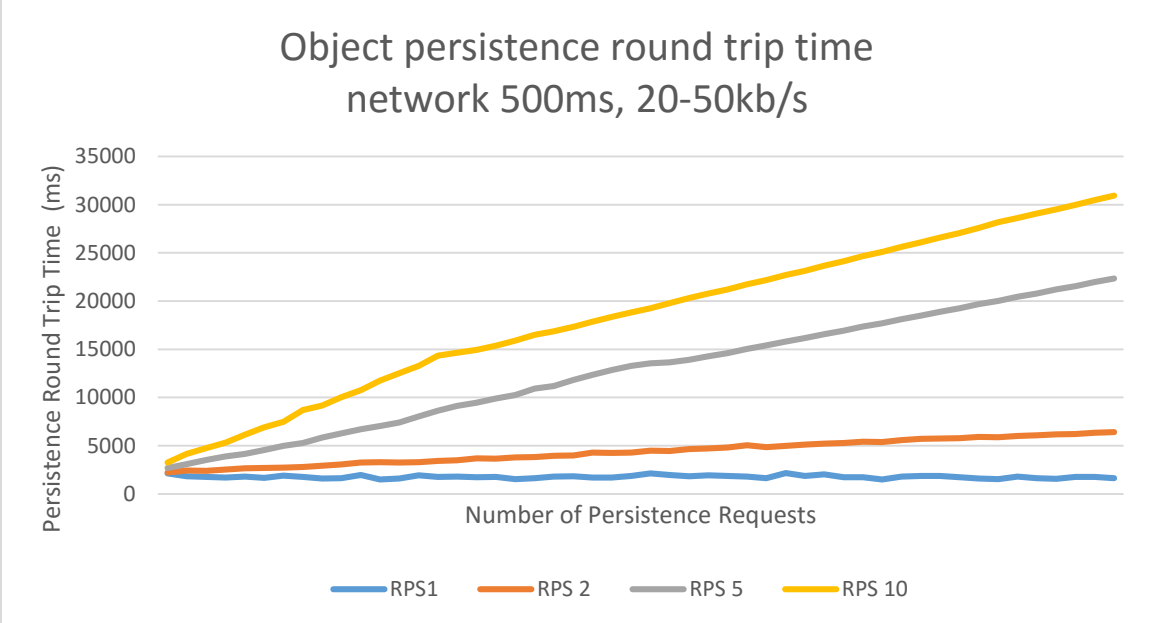

Figure 24: Round trip time vs modification frequency in GPRS network 500ms, 20-50kb/s

According to Figure 24, for higher object modification frequencies of 5 and 10 requests per second, persistence round trip time of individual object modification increases rapidly going beyond 12 seconds, which is the time limit [19] where users begin to doubt whether the web application is malfunctioning.

To understand the effect of network performance, for object persistence round trip time, next two experiments are carried increasing the network performance. Figure 25 and Figure 26, shows the results of the experiment.

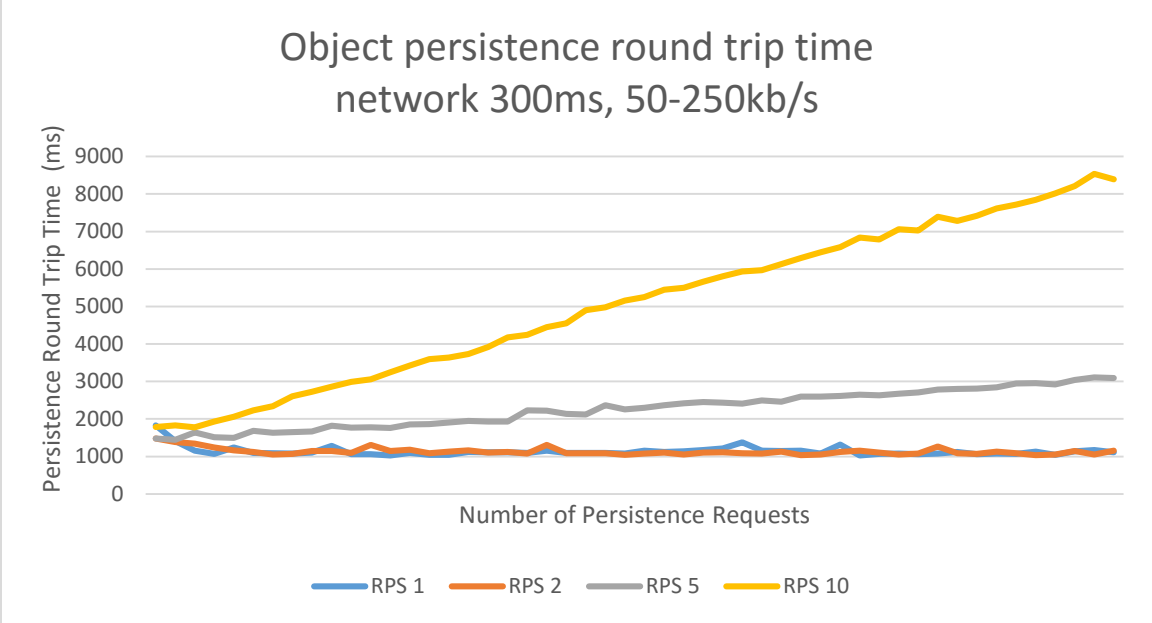

Figure 25: Round trip time vs modification frequency in regular 2G network 300ms, 50-250kb/s

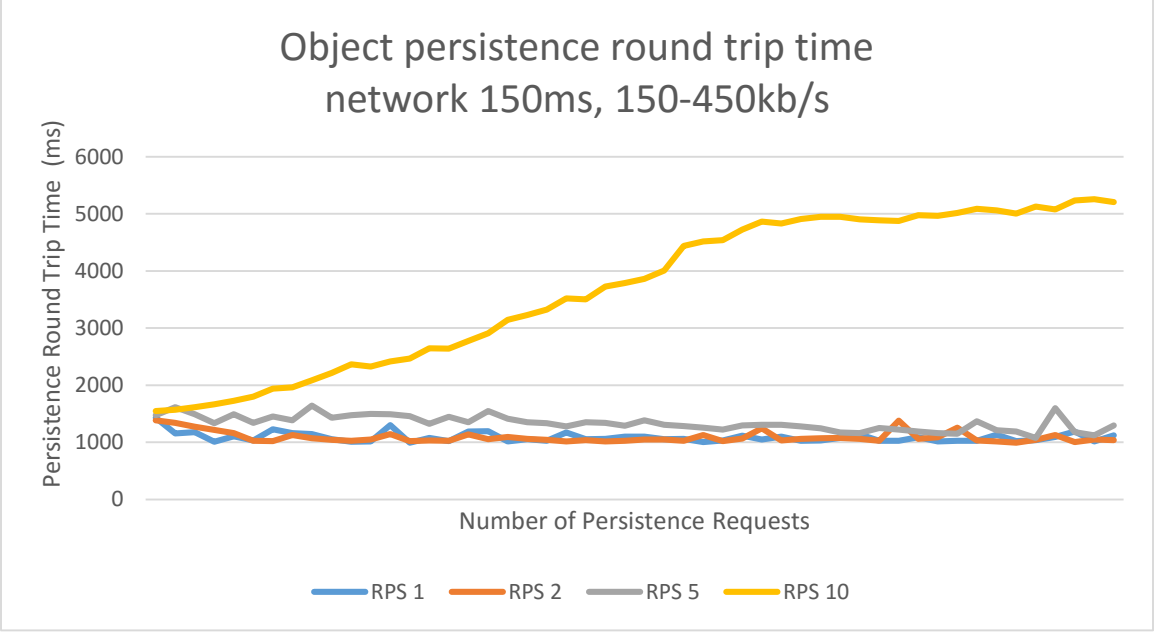

Figure 26: Round trip time vs modification frequency in good 2G network 150ms, 150-450kb/s

According to the Figure 25 & 26 shown above, increase in network performance reduces object persistence round trip time. In these two network simulations only the highest frequency of 10 object modifications per second goes beyond the accepted response time limit. Based on the direct persistence results observed, object persistence round trip time has the following relationship.

$$Object\ Persistence\ Round\ Trip\ Time\ \propto \frac{Object\ Modification\ Frequency}{Network\ Performance}$$

Increase in frequency affects the persistence round trip time, proportionally for higher frequencies. The network speed affects the round trip time inverse proportionally.

4.2 Persisting objects with fixed persistence time window

Since the most significant increase on persistence timing occurred with the GPRS network performance of 500ms, 50-250kb/s and persistence frequency of 10 object modification requests per second, further experiments are carried out adding different persistence time windows. Figure 27 shows how object persistence round trip time changes with persistence window sizes of 100ms, 200ms, 500ms, 1000ms and 2000ms in comparison with not having a persistence time window.

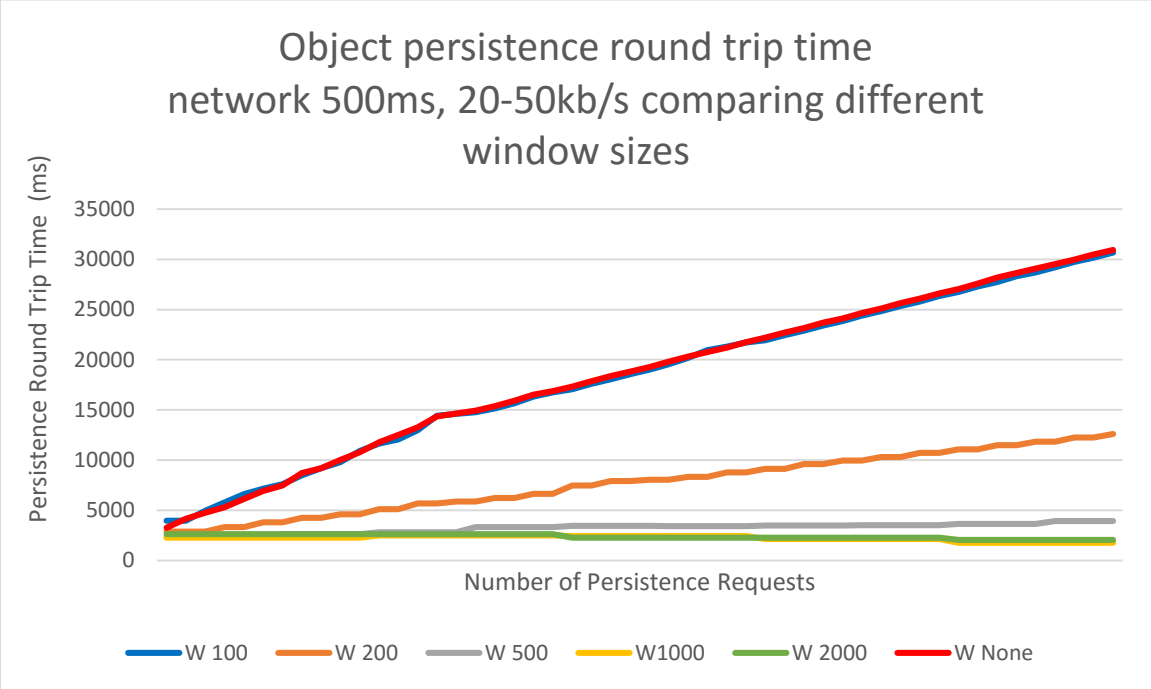

Figure 27: Round trip time vs persistence window size, 10req/s in GPRS network 500ms, 20-50kb/s

By adding a persistence time window, it reduces the congestion of network by only persisting the last modified object within a time frame. This has a similar effect as reducing the object modification frequency. As shown in Figure 27, when the persistence window size gets closer to the object modification frequency, the effect in addition of the persistence time window is hardly noticeable. However, by increasing the persistence

window size above object modification frequency, it is clearly reducing the object persistence round trip time. In fact, best object persistence round trip time, for the least persistence window size happens at the persistence window size of 1000ms. Further increasing persistence window size does not reduce the persistence round trip time for the given frequency.

If we define a parameter called total persistence time of an object where,

$$Total\ persistence\ time\ of\ an\ object = waiting\ time\ in\ persistence\ window + persistence\ round\ trip\ time$$

Figure 28, shows how total persistence time of an object changes with total round trip time average.

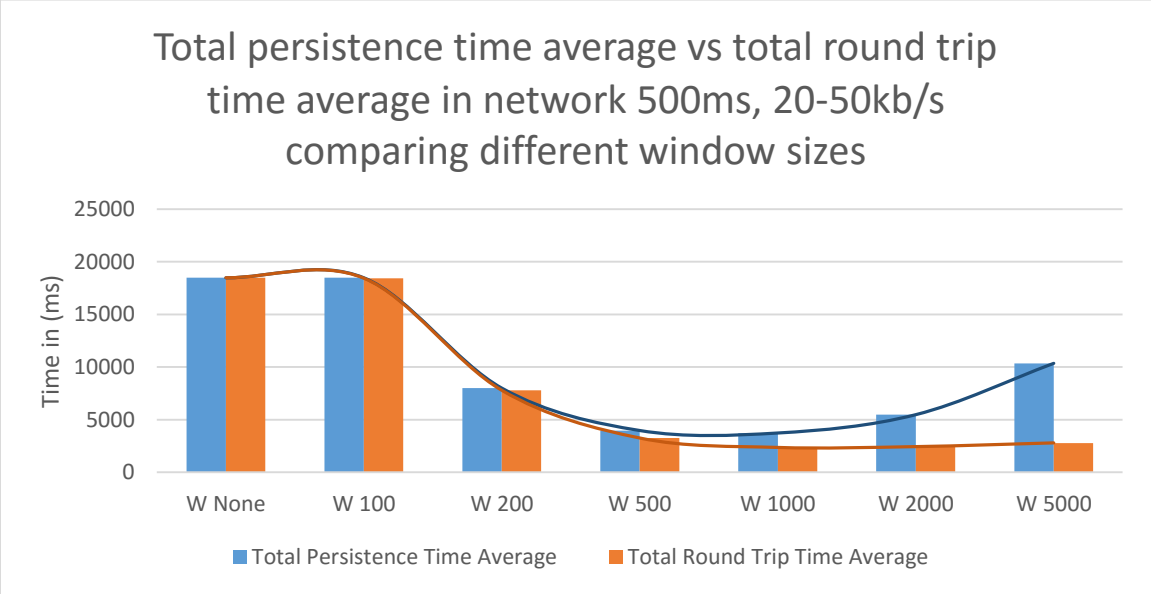

Figure 28: Total persistence time average vs total round trip time, 10req/s in GPRS network 500ms, 20-50kb/s

The downside of increasing the persistence window size is that the objects are getting stalled in the web browser client and beyond the certain point, it increases the actual

persistence round trip time. This is because the object needs to wait a time interval of the window size before sent for persistence service. According to Figure 28, minimal value of the total object persistence time average and the total round trip time average is achieved at the persistence window size of 1000ms. Increasing the persistence window size beyond 1000ms, total persistence time average increases. Therefore, it requires to select a suitable size for the persistence time window to frequently persist the objects to the persistence service, but not too quick to congest the network or hit the throttling limit of the persistence service, which will increase the individual round trip time and total persistence time average.

4.3 Persisting objects with dynamic persistence time window

In web applications, object modification frequencies are not fixed and also network performance and server throttling limits can vary drastically. Still persisting high frequency object modifications in slow networks is a challenge. Previous experiments clearly shown that adding a persistence time window can reduce the object persistence round trip time. However, to improve the object persisting performance web applications, it is required to come up with a mechanism to calculate a dynamic persistence window size to reduce, network congestion and reaching persistence service limits.

4.3.1 Adjusting persistence window size

To adjust the dynamic persistence window size, several algorithms were initially considered.

Window RTT Average [WRTT (m)] $= \frac{\sum_{x=1}^{x=m} RT(x) + W(x) - ST(x)}{\sum_{x=1}^{x=m} x}$

Request RTT for request **m,** [RTT (m)] $= RT(x) - ST(x)$

Where:

ST(x) = Start request time, RT(x) = Response received time, W(x) = Modification window size for a request **x**.

In the first approach dynamic persistence window size is calculated as

W_{size} is, dynamic persistence time window after **m** requests

If $RTT(m) - Average(WRTT(m)) > \Delta RTT_{threshold}$, Then

$W_{size}(m) = W_{size}(previous) + \Delta W_{increment}$

Else

$W_{size}(m) = MAX((W_{size}(previous) - \Delta W_{decrement}), 0)$

End

Where:

Round trip time threshold = $\Delta RTT_{threshold}$, Predicted next request round trip time = $RTT_{predicted}(m+1)$, Modification window threshold = $\Delta W_{threshold}$, Modification window increment = $\Delta W_{increment}$, Modification window decrement = $\Delta W_{decrement}$

This algorithm worked for medium object modification frequencies. However, when the object modification frequency becomes higher, and the algorithm operates for longer period of time, Average (WRTT (m)) increases. The average round trip time further increases with the addition of persistence time window. Since the persistence window is increased only according to the following condition,

$$RTT(m) - Average\ (WRTT\ (m)) > \Delta RTT\ threshold$$

With the increase in the number of object persistence requests, cumulative persistence window size increase becomes less. More modifications were done to optimize the persistence algorithm by rotating conditional parameters such as average, maximum and minimum round trip times, calculated after each persistence round trip. However, these modifications didn't provide satisfactory results.

Then a new approach is considered by predicting next round trip time, using polynomial regression which is being used to adjust the window size. As shown in the following equation, $RTT_{predicted}(m+1)$ and current RTT difference was considered and if it goes beyond a certain threshold, the persistence window size is adjusted. Here a threshold is used to minimize the window size change, due to small random variations of round trip time.

If $RTT_{predicted}(m+1) - RTT(m)) > \Delta RTT_{threshold}$, Then

$W_{size}(m) = W_{size}(previous) + \Delta W_{increment}$

Else

$W_{size}(m) = MAX((W_{size}(previous) - \Delta W_{decrement}), 0)$

End

$RTT_{predicted}(m+1)$ prediction was fairly accurate and improved with the number of persistence requests, since the coefficients of the polynomial regression is calculated after each persistence roundtrip. Figure 29 shows the predicted value and actual value for each roundtrip time calculated for object modification frequency 10req/s in GPRS network 500ms, 20-50kb/s.

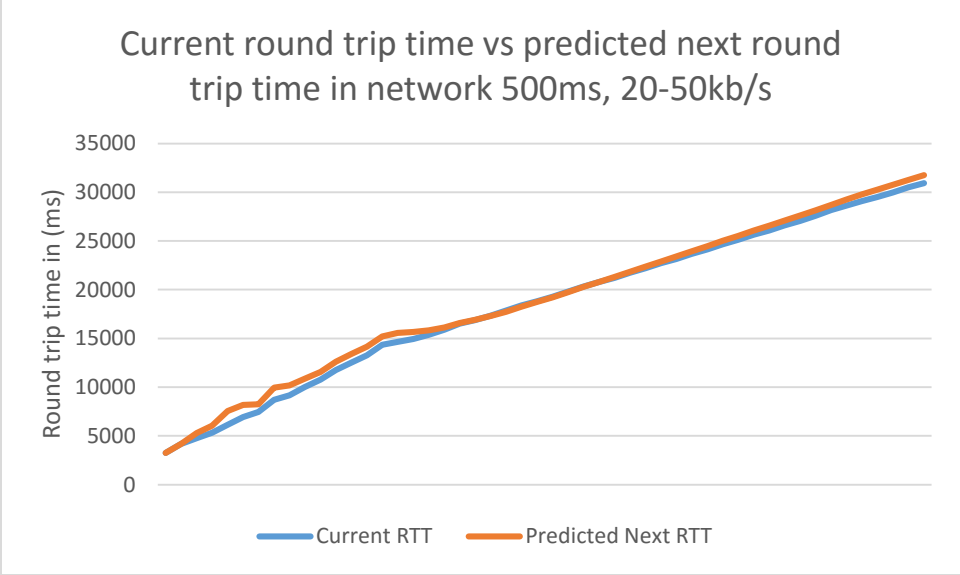

Figure 29: Current round trip time vs predicted next round trip time

4.3.2 Dynamic persistence time window experiment results

Similar to fix persistence time window experiments, GPRS network performance of 500ms, 50-250kb/s and persistence frequency of 10 object modification requests per second is used for dynamic persistence time window experiments.

After carrying out the experiment with dynamic persistence window size calculation, it was observed that, if the request frequency is high compared to the persistence round trip time, too many requests are being sent initially (Before persistence window size is calculated) which increases the persistence round trip time of all the object persistence requests, overall not getting the optimal results we found in the fixed persistence time window.

Therefore, the experiment is carried out by adding initial persistence window sizes for the dynamic persistence time window to compare it with fixed persistence time window algorithm and the results are shown in Figure 30.

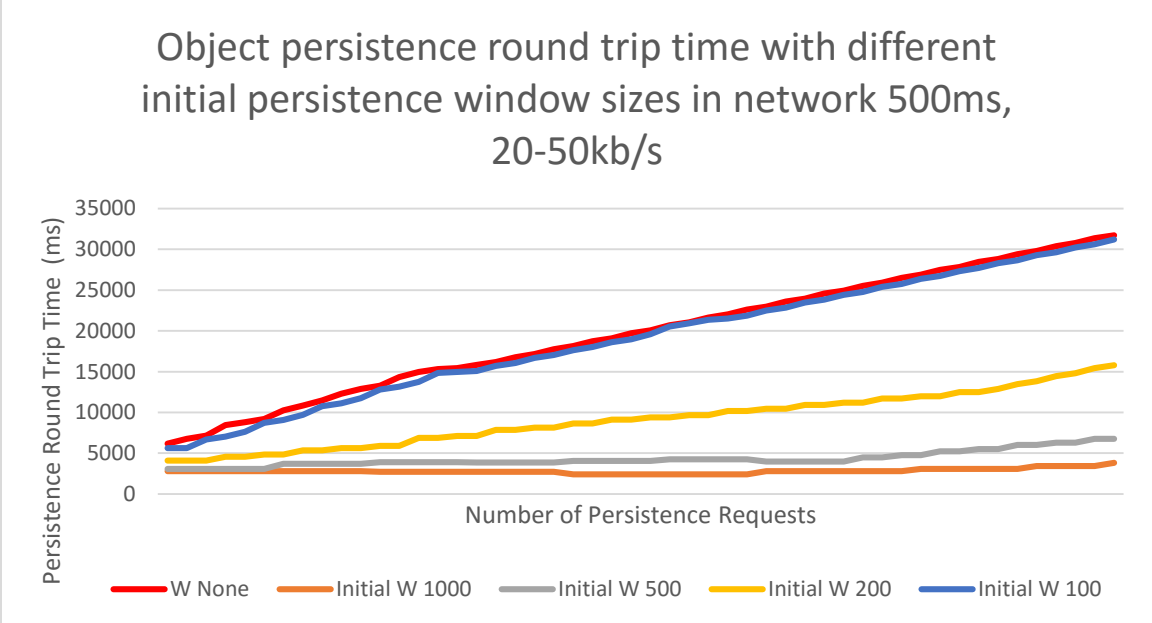

Figure 30: Object persistence round trip time with different initial persistence window sizes in dynamic persistence time window

Both fixed time window and dynamic time window experiments shown better round trip time (less is better) comparable to directly persisting objects for higher object persisting frequencies. It is also observed that the round trip time in the dynamic persistence time window with an initial persistence window size, is slightly higher compared to the same size of the fixed persistence time window for consistent object persistence frequencies.

Although the object persistence round trip time is slightly higher in the dynamic persistence window model compared to fixed persistence window model, according to the Figure 31, dynamic persistence window model, reduces the total persistence time of an object when persistence window size increases. This is because, for large window sizes, in the fixed

persistence window, all the objects need to wait a maximum window size before the actual persistence round trip happens.

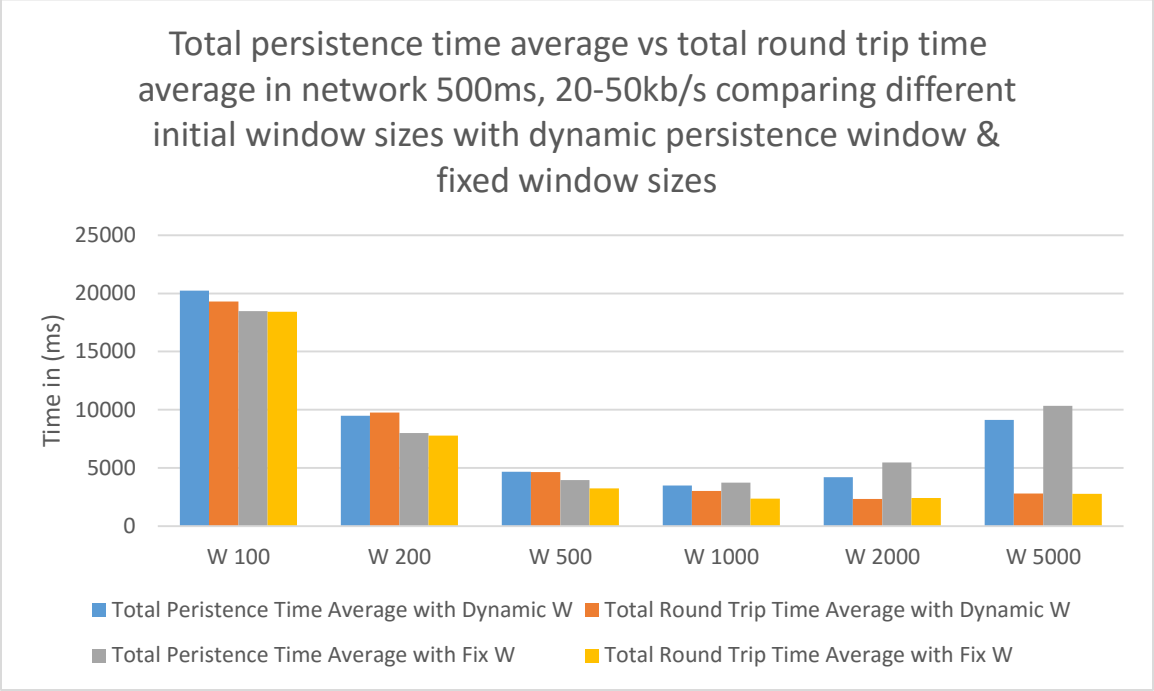

Figure 31: Total persistence time average vs total round trip time average in fixed window & dynamic window persistence models

4.4 Conclusion & future work

After conducting several experiments by simulating a web application with high frequent object persistence request workloads, it was found that, the object persistence round trip time gets higher with the increase of persistence frequency. In a slow network, it can even go beyond user acceptance limits where the user will think the web application is not responding. It was found that this is mainly due to the increase in network congestion and persistence web service throttling limits.

The adaptive object persistence JavaScript framework implemented in this research, reduces the persistence round trip time by persisting the last modification of the object within a time window. This reduces the number of object modifications sent to the persistence web service, regardless of the number of times, the object got modified within a time interval.

In web applications, object persistence frequencies are generally based on user interactions that varies with time. This makes it challenging to find an optimal fixed window size. In this research, it was found that, using polynomial regression with an order of 3, it is possible to predict the next object persistence round trip time with a reasonable accuracy, based on past round trip time data. Using the predicted next round trip time direction, it was possible to adjust the persistence window size, to reduce the object persistence round trip time, for varying object persistence frequencies. Therefore, in comparison to fixed persistence window model, the dynamic persistence window model is more suitable for web applications since it provides less overhead for low object persistence frequencies while reducing network congestion and persistence service usage for higher object persistence frequencies.

However, for web applications like games, where it is possible to have initial higher frequencies for object persistence, it is required to select an initial persistence window size. Otherwise, even with the dynamic persistence window model, many object modification requests are immediately sent to the persistence service before window size is adjusted upon receiving the persistence response. Therefore, further research needs to be carried out, using the experimental data to select a suitable initial persistence window size for web applications.

To further improve the dynamic persistence window calculation algorithm, it requires to deploy the adaptive persistence window JavaScript framework developed, for functioning

web applications and collect operational data similar to the experimental data collected in this research. This data can be further analyzed to adjust the algorithm parameters such as round trip time threshold, increment and decrement to further improve its performance.

Furthermore, this research can be extended to optimize other web service invocations by combining all the requests arrived within a time window and sending them to the web service at the end of the window time interval.

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Appendix A: Experimental results - Without persistence window

Object persistence round trip time in network 500ms, 20-50kb/s
RPS (Requests per second) with averaging 3 experiments

Req. No	RPS1	RPS2	RPS 5	RPS10	Req. No	RPS1	RPS2	RPS5	RPS10
1	2129	2231	2684	3250	26	2119	4504	13543	19274
2	1826	2435	3110	4169	27	1970	4465	13657	19797
3	1763	2402	3530	4771	28	1836	4672	13920	20322
4	1702	2531	3881	5309	29	1936	4718	14271	20770
5	1794	2650	4150	6144	30	1867	4834	14621	21219
6	1655	2699	4574	6930	31	1808	5045	15046	21744
7	1899	2746	4996	7464	32	1643	4857	15393	22190
8	1763	2792	5271	8705	33	2168	4979	15823	22716
9	1617	2920	5849	9181	34	1853	5107	16168	23158
10	1642	3051	6276	10017	35	2025	5234	16586	23682
11	1967	3252	6699	10777	36	1726	5281	16932	24124
12	1513	3298	7051	11765	37	1750	5407	17356	24661
13	1602	3264	7402	12521	38	1504	5372	17701	25103
14	1929	3310	8049	13284	39	1794	5580	18134	25632
15	1784	3439	8638	14355	40	1864	5703	18486	26081
16	1800	3482	9136	14646	41	1882	5758	18900	26595
17	1743	3682	9480	14935	42	1742	5799	19247	27049
18	1763	3652	9911	15386	43	1606	5917	19679	27576
19	1540	3778	10258	15907	44	1546	5890	20020	28178
20	1634	3823	10921	16520	45	1793	6014	20445	28627
21	1806	3951	11183	16884	46	1650	6068	20797	29075
22	1823	3994	11839	17330	47	1586	6191	21218	29513
23	1691	4279	12346	17850	48	1768	6232	21565	29964
24	1700	4247	12854	18379	49	1776	6356	21984	30491
25	1867	4298	13275	18831	50	1636	6404	22337	30940

Object persistence round trip time in network 300ms, 50-250kb/s
RPS (Requests per second) with averaging 3 experiments

Req. No	RPS1	RPS2	RPS5	RPS10	Req. No	RPS1	RPS2	RPS5	RPS10
1	1833	1476	1477	1788	26	1157	1074	2302	5254
2	1408	1382	1441	1832	27	1123	1101	2367	5445
3	1156	1340	1644	1777	28	1135	1054	2419	5495
4	1073	1241	1514	1928	29	1172	1101	2451	5661
5	1236	1164	1497	2061	30	1215	1116	2439	5803
6	1091	1117	1682	2228	31	1374	1085	2407	5932
7	1090	1055	1633	2344	32	1151	1081	2494	5971
8	1080	1070	1652	2607	33	1149	1133	2464	6134
9	1105	1148	1667	2723	34	1157	1039	2593	6289
10	1281	1145	1818	2859	35	1077	1050	2600	6443
11	1059	1097	1771	2992	36	1313	1117	2615	6580
12	1059	1305	1774	3060	37	1030	1158	2649	6834
13	1030	1149	1761	3244	38	1072	1101	2632	6788
14	1096	1179	1858	3429	39	1075	1055	2671	7060
15	1046	1085	1861	3597	40	1058	1074	2705	7028
16	1042	1128	1908	3634	41	1076	1263	2788	7393
17	1121	1164	1946	3736	42	1124	1086	2805	7281
18	1108	1100	1930	3920	43	1064	1067	2809	7416
19	1108	1117	1933	4177	44	1075	1130	2846	7615
20	1092	1078	2226	4247	45	1073	1086	2944	7714
21	1152	1312	2224	4448	46	1125	1039	2958	7849
22	1091	1085	2134	4549	47	1040	1056	2925	8015
23	1095	1086	2117	4902	48	1139	1145	3043	8214
24	1096	1085	2367	4974	49	1169	1053	3108	8535
25	1081	1040	2252	5159	50	1109	1155	3096	8389

Object persistence round trip time in network 150ms, 150-450kb/s
RPS (Requests per second) with averaging 3 experiments

Req. No	RPS1	RPS2	RPS5	RPS10	Req. No	RPS1	RPS2	RPS5	RPS10
1	1427	1387	1474	1549	26	1097	1047	1384	3862
2	1156	1339	1616	1569	27	1054	1048	1306	4006
3	1179	1273	1488	1614	28	1057	1027	1285	4437
4	1009	1215	1336	1666	29	1004	1129	1253	4514
5	1103	1158	1492	1726	30	1029	1020	1219	4537
6	1032	1023	1337	1799	31	1118	1065	1296	4724
7	1225	1022	1452	1939	32	1048	1244	1306	4865
8	1158	1126	1385	1964	33	1101	1030	1304	4828
9	1144	1068	1642	2082	34	1024	1059	1277	4911
10	1051	1045	1430	2215	35	1034	1070	1242	4945
11	1011	1028	1476	2365	36	1075	1075	1173	4946
12	1012	1049	1494	2328	37	1136	1060	1161	4900
13	1298	1142	1493	2417	38	1027	1028	1250	4887
14	992	1021	1458	2465	39	1026	1381	1224	4873
15	1077	1034	1324	2645	40	1089	1062	1188	4973
16	1020	1028	1446	2638	41	1016	1085	1162	4966
17	1186	1138	1353	2773	42	1027	1253	1148	5013
18	1195	1056	1546	2909	43	1024	1034	1367	5089
19	1015	1091	1413	3145	44	1133	1017	1212	5057
20	1051	1062	1352	3229	45	1022	993	1189	5002
21	1028	1040	1334	3321	46	1035	1043	1078	5127
22	1173	1016	1278	3520	47	1093	1128	1599	5075
23	1054	1037	1350	3502	48	1187	1003	1179	5232
24	1062	1016	1342	3724	49	1012	1048	1120	5257
25	1101	1028	1289	3789	50	1123	1035	1293	5204

Appendix B: Experimental results - With different fixed persistence window sizes

Object persistence round trip time in network 500ms, 20-50kb/s, 10 requests per second for different fixed persistence window sizes in milliseconds with averaging 3 experiments

Req. No	W 100	W 200	W 500	W 1000	W 2000	Req. No	W 100	W 200	W 500	W 1000	W 2000
1	3953	2895	2366	2268	2640	26	19024	8062	3466	2451	2276
2	3953	2895	2366	2268	2640	27	19537	8062	3436	2451	2276
3	4947	2895	2366	2268	2640	28	20187	8334	3436	2451	2276
4	5788	3320	2366	2268	2640	29	20947	8334	3436	2451	2276
5	6617	3320	2366	2268	2640	30	21312	8765	3436	2451	2276
6	7144	3822	2366	2268	2640	31	21733	8765	3436	2451	2276
7	7587	3822	2632	2268	2640	32	21927	9117	3489	2153	2276
8	8505	4245	2632	2268	2640	33	22450	9117	3489	2153	2276
9	9182	4245	2632	2268	2640	34	22895	9596	3489	2153	2276
10	9791	4593	2632	2268	2640	35	23422	9596	3489	2153	2276
11	10900	4593	2632	2268	2640	36	23862	9952	3489	2153	2276
12	11654	5099	2830	2514	2640	37	24386	9952	3527	2153	2276
13	12062	5099	2830	2514	2640	38	24832	10298	3527	2153	2276
14	12976	5675	2830	2514	2640	39	25356	10298	3527	2153	2276
15	14408	5675	2830	2514	2640	40	25796	10721	3527	2153	2276
16	14606	5868	2830	2514	2640	41	26327	10721	3527	2153	2276
17	14782	5868	3345	2514	2640	42	26769	11075	3652	1778	2068
18	15149	6217	3345	2514	2640	43	27293	11075	3652	1778	2068
19	15670	6217	3345	2514	2640	44	27740	11495	3652	1778	2068
20	16319	6648	3345	2514	2640	45	28312	11495	3652	1778	2068
21	16757	6648	3345	2514	2640	46	28706	11835	3652	1778	2068
22	17078	7461	3466	2451	2276	47	29204	11835	3939	1778	2068
23	17610	7461	3466	2451	2276	48	29749	12259	3939	1778	2068
24	18042	7929	3466	2451	2276	49	30173	12259	3939	1778	2068
25	18567	7929	3466	2451	2276	50	30686	12608	3939	1778	2068

Appendix C: Experimental results - With dynamic persistence window having initial window sizes

Object persistence round trip time in network 500ms, 20-50kb/s, 10 requests per second for different dynamic persistence window with initial window sizes in milliseconds

Req. No	Initial W1000	Initial W500	Initial W200	Initial W100	Req. No	Initial W1000	Initial W500	Initial W200	Initial W100
1	2794	3078	4079	5606	26	2413	4046	9408	19582
2	2794	3078	4079	5606	27	2413	4246	9408	20552
3	2794	3078	4079	6676	28	2413	4246	9667	20917
4	2794	3078	4580	7040	29	2413	4246	9667	21362
5	2794	3078	4580	7641	30	2413	4246	10169	21529
6	2794	3078	4848	8722	31	2413	4246	10169	21886
7	2794	3699	4848	9088	32	2802	3977	10436	22500
8	2794	3699	5349	9687	33	2802	3977	10436	22855
9	2794	3699	5349	10753	34	2802	3977	10940	23469
10	2794	3699	5617	11133	35	2802	3977	10940	23822
11	2794	3699	5617	11730	36	2802	3977	11208	24432
12	2717	3899	5884	12792	37	2802	4480	11208	24793
13	2717	3899	5884	13163	38	2802	4480	11712	25397
14	2717	3899	6865	13762	39	2802	4747	11712	25764
15	2717	3899	6865	14844	40	3065	4747	11979	26370
16	2717	3899	7134	14971	41	3065	5247	11979	26735
17	2717	3859	7134	15100	42	3070	5247	12479	27344
18	2717	3859	7876	15712	43	3070	5515	12479	27703
19	2717	3859	7876	16071	44	3070	5515	12869	28305
20	2717	3859	8129	16679	45	3070	6017	13481	28670
21	2717	3859	8129	17041	46	3437	6017	13841	29286
22	2413	4046	8637	17643	47	3437	6286	14454	29642
23	2413	4046	8637	18009	48	3437	6286	14812	30241
24	2413	4046	9130	18617	49	3437	6747	15422	30610
25	2413	4046	9130	18980	50	3805	6747	15784	31221