Web for Wearables: Lessons learned from Google Glass

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ABSTRACT
This paper presents a first look at some of the challenges associated with enabling a seamless web experience on Optical Head Mounted Display wearables such as Google Glass from the perspective of web content providers, client device, and the network. We conducted experiments to study the impact of choosing the application layer protocol (e.g., HTTP vs HTTPS) and of individual web components on the performance of Glass browser, by measuring webpage load time, temperature variation and power consumption and compare it to a smartphone. Our findings suggest that (a) performance of Glass compared to a smartphone in terms of total power consumption and webpage load time deteriorates with increasing number of web objects, number of servers accessed and number of JavaScripts on a webpage, (b) execution time for popular JavaScript benchmarks is about 3 to 8 times higher on Glass compared to a smartphone, (c) popular 3rd party analytics and ad scripts on Glass takes about 2x more time to execute than a smartphone (d) WebP is an energy efficient image format compared to JPEG and PNG on Glass, (e) cost of HTTPS on Glass compared to a smartphone increases with increasing number of web objects, webpage size and the number of servers accessed on a webpage, and (f) seven out of 50 websites studied in this paper are providing better wearable web experience by specifically serving fewer or smaller images, fewer JavaScripts, fewer CSS and no ads to Glass than a smartphone.

Categories and Subject Descriptors
C.4 [Computer Systems Organization]: Performance of Systems

Keywords
Wearable computing, Internet of things, Google Glass

1. INTRODUCTION
Over the past two decades, the World Wide Web has undergone a huge transformation, evolving from basic webpages with hyperlinks to a substantially more complex ecosystem with dynamic webpages and dynamic content delivery models. Accessing a modern webpage results in multiple web resources including complex JavaScripts and Cascading Style Sheets (CSS) being downloaded from multiple network servers. While the web ecosystem has become complex, the devices accessing the web are becoming smaller, moving from desktop to tablets to smartphone and with wearables possibly becoming the next “killer” device. The trade-off between ever increasing web complexity and gradual miniaturization of devices having limited processing capabilities posits an open question worth investigating: How does the current web ecosystem impact the performance of wearable devices? In this paper, we take a first stab at answering this question by considering a popular Optical Head Mounted Display device: Google Glass.

We study how Glass copes with the current web ecosystem by quantifying the Glass web browsing performance and comparing it to a Nexus 5 smartphone. A profiler is developed for both Glass and smartphone to monitor several performance metrics such as power consumption, temperature variation, number of download bytes and webpage load time while loading the webpages. A series of experiments are conducted using the 802.11 WiFi radio technology. The initial experiment consists of accessing a total of 50 popular websites under various categories from Alexa Top 500. The next set of experiments deals with loading synthetic webpages, executing popular JavaScript benchmarks and loading different image formats. The final experiment is to access the websites measured in the initial experiment using HTTPS. Additionally, we analyzed tcpdumps and examined the web objects served by 50 websites to find if they provide different web experience to Glass and smartphone. We also discuss ways in which web content can be delivered better to Glass.

Based on our experiments, we highlight the following important results:

• The performance of Glass compared to a smartphone in terms of total power consumption and webpage load time deteriorates with increasing number of web objects, number of servers accessed and number of JavaScripts on a webpage. The webpage load time for the landing page of popu-
lar websites is very high (2x on average) on Glass compared to a smartphone. However, 2x higher webpage load time only results in 1.2x (on average) higher total power consumption on Glass due to a lower rate of power consumption than a smartphone.

- Among the web components, fetching and execution of JavaScripts is the largest contributor to the webpage load time. The Glass browser is about 3 to 8 times slower than the Chrome browser on a Nexus 5 smartphone, while executing the same JavaScript benchmarks. The execution time for 3rd party analytics and ad scripts on Glass is about 2x that of smartphone.

- The WebP image format is more energy efficient on Glass compared to JPEG and PNG. For example, using WebP instead of JPEG on m.wikihow.com results in 45% savings in power consumption and 50% lower webpage load time.

- The cost of accessing a website using HTTPS on Glass when compared to a smartphone increases with increasing number of web objects on a webpage, webpage size and the number of servers accessed through the webpage. For instance, Glass power consumption is 27% lower than smartphone for webpages with less than 64 web objects. However, the power consumption on Glass becomes 17% higher than that of smartphone when loading webpages having more than 64 web objects.

- Surprisingly, in our study, we found that seven out of the 50 studied websites have already been optimized for content delivery to Google Glass. For example, m.espn.go.com optimize by serving images according to the Glass viewport dimensions.

The rest of the paper is organised as follows. Section 2 discusses related work. Section 3 explains experimental setup. Performance results are discussed in Section 4. We provide recommendations for content delivery on wearables in Section 5. Finally, Section 6 concludes the paper.

2. RELATED WORK

Michael et al. [7] demonstrated the increasing complexity of webpages by characterizing 2000 websites landing pages on a desktop from four geographically distributed vantage points. The number of requested web objects and the number of non-origin sources were found to have the highest impact on the webpage load time. Xiao et al. [10] developed a tool named WProf, which can profile web browser activities on a desktop. The findings suggest that synchronous JavaScript plays a prominent role in webpage load time and caching does not reduce the webpage load time in direct proportion to the number of cached objects.

Thiagarajan et al. [9] created a system to measure mobile browser energy for few popular websites. On the basis of experiments, the authors provide recommendations on designing better webpages. Wang et al. [11] analysed how techniques like client-side caching, prefetching and speculative loading can improve mobile browser performance. Qian et al. [8] found that factors including protocol overhead, webpage content, caching and traffic timing at different layers affect resource utilization for mobile web browsing. We think that similar performance related studies like ours might be beneficial in the context of wearables.

3. EXPERIMENTAL SETUP

The experimental setup consists of a Google Glass, a Nexus 5 smartphone and a laptop. Figure 1 shows the setup. In general, our experiments can be broadly divided into two categories: accessing real webpages on the Internet from Glass and smartphone, and accessing synthetic webpages hosted on a local Apache web server running on a laptop from Glass. All experiments use WiFi. The synthetic webpages are created for two scenarios: (a) Hosting landing pages of websites that are considered for studying the impact of various web components on browsing experience, and (b) Image format comparison experiments. Hosting webpages on a local server provides a way to control webpage content according to experimental needs. More details are presented later in Section 4.2.1 and 4.2.3. While serving the web requests, laptop does not do any significant processing tasks which can skew the accuracy of the measurements.

![Figure 1: Experimental Setup](image)

We created an application for both Glass and smartphone, which invokes the browser with the website url to be accessed as an input. Browser cache is emptied before each experiment.

We also developed a profiler app for both Glass and smartphone. Profiler runs in the background and col-\footnote{The laptop runs Mac OS X, has 8 GB of RAM and 2.6 GHz processor.}
lects the following performance metrics every second and writes them to a file with timing information for later analysis:

- **Power:** The current and voltage are obtained by reading `current_now` and `voltage_now` files respectively located at `/sys/class/power_supply/battery`. The power consumption is then calculated by multiplying the current and voltage.

- **Device temperature for Glass:** CPU board temperature is obtained by reading `/sys/devices/platform/notepad_sensor.0/temperature` file.

- **Downloaded bytes:** `getUidRxBytes` and `getUidTxBytes` functions from traffic stats class (Android framework) are used to report the received and transmitted bytes respectively by the browser.

- **Webpage load time:** Webpage load time is measured from the time of first DNS request (start time) to the time when browser receives the last web object (end time). The profiler extracts the start and end time from the browser logs.

All the experiments are repeated six times and the results reported are averages unless stated otherwise. Each experiment is first performed on Glass and on the completion of the experiment, the same experiment is immediately repeated on smartphone. The measurements on the devices are taken when they are not connected to any external device and when their battery is fully charged. Glass is always allowed to cool down to 37 degrees celsius or less before commencing experimentation to prevent aggressive dynamic voltage frequency scaling (DVFS) from kicking in. DVFS kicks aggressively on Glass at 55 degree celsius. The Glass is worn by a user during the experiments. To get accurate measurements, no other apps except the profiler, app to invoke the browser and the browser are running on the devices.

4. RESULTS

4.1 Browser Performance for Popular Websites

Our first experiment studies the impact of accessing popular websites on Glass browser performance and compare it to a smartphone browser. Overall, the focus is to find out how the complexity of webpages affects the relative performance between Glass and smartphone. According to a recent report from Adobe [1], the top categories of websites being accessed from Glass are media and entertainment with sports being the most popular sub category along with news, informational and technology. We picked 50 popular websites from Alexa Top 500 under the aforementioned categories. We observed that seven websites have been optimized for content delivery on Glass and are hence discussed separately in Section 4.4.

To better understand what causes the performance differences between Glass and smartphone, we did a correlation analysis for three performance metrics: relative total power consumption, relative webpage load time, and temperature variation on Glass against factors representing a modern website’s landing webpage complexity: number of web objects, number of servers contacted, total bytes, number of JavaScripts, number of CSS and number of images. The results are shown in Figure 2.

Across all three performance metrics, we see that the three most correlated web complexity factors are the total number of web objects loaded, the number of Javascripts within these objects, and the number of servers contacted while loading the page. The correlation coefficient for the aforementioned web complexity factors is in the range of 0.6 to 0.8, which indicates a very high correlation. As Glass is computationally less powerful than a smartphone, the performance gap increases with every connection a browser has to create to fetch a web component, which is totally determined by the number of web objects and the number of servers to be accessed. Amongst the web components, the highest impact on the relative performance is caused by the number of Javascripts. The reason is the resource intensiveness of the JavaScript compared to the other web components, which will be shown in the next section.

![Figure 2: Correlation Analysis](image-url)

Figure 2 further visually confirms the strong correlation between three performance metrics and the number of web objects requested. Here, we bin websites based on the number of web objects requested from their landing webpage. Then, for each bin, we construct a box-and-whiskers plot showing the median, 25th percentile, and 75th percentile plot in the “box” and the min/max values for the whiskers. The total power consumption...
and webpage load time for Glass in comparison to a smartphone deteriorates with the increasing number of web objects. The same holds true for temperature rise on Glass. Accessing \texttt{nb.com} causes the temperature to rise by as high as 7.5 degrees. In conclusion, we can say that the performance cost of accessing websites can be reduced drastically on Glass by designing webpages having a small number of web objects (number of JavaScripts as less as possible) being fetched from fewer network servers.

### 4.2 Browser Performance for Web Components

In order to understand how the design of today’s popular websites affects the browser performance on Glass, we consider a set of three different experiments. First, we measured the webpage load time and power consumption for three key HTML elements: CSS, JavaScript and Images for the synthetic landing webpage of websites on Glass. Second, we measure the execution time of popular JavaScript benchmarks, analytics and ad scripts on Glass and smartphone. Third, we study the power consumption of different image formats such as JPEG, PNG and WebP on Glass.

#### 4.2.1 Synthetic WebPages: Breakdown Analysis by Web Components

To conduct our experiments, we created a copy of the website landing pages on a local Apache web server having version 2.2.29. Note that the local server only contains a copy of website landing HTML page, which is fetched by the Glass browser. All other web objects embedded inside the webpage are still served by the original servers to the Glass browser. We chose to do so because modern websites are complex and have dynamic content, which makes it impractical to store each and every web object embedded inside the website landing page on the local server. This also ensures that our experimental setup remains simple and does not affect the way in which the web content is fetched usually from the Internet by a device. The local HTML copy of the website landing page allows us to systematically add or remove web components that are accessible from the Glass browser. The energy consumed by each web element is estimated by comparing the energy consumption used for loading the entire webpage to the energy consumption needed for loading the webpage with a specific type of web component removed by filtering it out from the HTML code. The difference between the two numbers gives us an estimate for the energy needed to load the web component of a certain type on a webpage. We followed two criteria while selecting websites for these experiments: (a) the website landing HTML page should not make any web object request to the local server, (b) images displayed on the landing page should not be triggered from a CSS or JavaScript on the webpage. The two preceding criteria prevents the skewness in measurements and ensures that our local server only gets a single request for the landing HTML webpage. In the end, 12 out of 50 websites passed both criteria.

The results are shown in Figure 4. The percent of power consumption by a web component is shown in Figure 4a. The “Others” category in the graph includes text and fonts. In general, JavaScript is the most power hungry component on Glass browser. We compare the JavaScript execution time across some popular benchmarks on Glass and smartphone. This provides an

### 4.2.2 JavaScript Benchmarks: Comparison

Our results so far suggest that JavaScript is the most power hungry component on Glass browser. We compare the JavaScript execution time across some popular benchmarks on Glass and smartphone. This provides an
estimate as to how slow Glass is compared to a smartphone when running the same JavaScript.

We chose SunSpider version 1.02 and Dromaeo suite as the JavaScript benchmark. SunSpider consists of 26 different JavaScripts and we executed all of them and found Glass/Browser to be 4x slower than Smartphone/Chrome browser. From Dromaeo suite, we executed Dromaeo JavaScript Tests, V8 JavaScript Tests, DOM Core Tests and JavaScript Library Tests. The results of the execution time for Dromaeo benchmark suite on each of the platforms are shown in Figure 5. The results show that Glass/Browser is about 3 to 8 times slower than Smartphone/Chrome browser, while executing the same JavaScript benchmarks. These results highlight the need to either have a faster JavaScript engine on Glass or today’s websites to serve less JavaScript to Glass.

We also measured the execution time for a few popular 3rd party analytic and ad scripts. The results are shown in Table 1. The execution time for 3rd party scripts on Glass is about 2x that of smartphone. Google Publishing Tag (gpt.js) is the most time consuming script which suggests that serving ads on Glass can cause significant delay in loading a webpage.

| JavaScript   | Smartphone (Seconds) | Glass (Seconds) |
|--------------|----------------------|-----------------|
| gpt.js       | 2.4                  | 4.22            |
| analytics.js | 0.3                  | 0.7             |
| ga.js        | 0.4                  | 0.8             |
| beacon.js    | 0.1                  | 0.2             |
| em.js        | 0.26                 | 0.62            |
| chartbeat.js | 0.19                 | 0.89            |

Table 1: Time to execute popular 3rd party analytic and ad scripts

4.2.3 Image Formats: Comparison and Optimization

JPEG and PNG are the most commonly used image format across the web. Recently, Google devised a new image format named WebP to download and render images faster than the existing image formats. We measured the energy consumption of PNG, JPEG and WebP image formats on Glass.

We used a JPEG image of size 500 KB. This JPEG image is then converted to smaller JPEG images and similar PNG and WebP images using cwebp. Each image is then embedded in a webpage that contains only the image. The webpage is hosted on local Apache web server. We measure the power consumption to download and render the different image formats. Figure 6

3https://developers.google.com/speed/webp/docs/cwebp
shows the energy consumption pattern.

![Figure 6: Power consumption for image formats - Glass](image)

The x-axis shows the image size of the JPEG image and y-axis shows the energy consumption for corresponding JPEG, PNG and WebP image formats. From the figure, it is clear that WebP is the most energy efficient format on Glass for all image sizes. The performance gaps between JPEG and WebP increases with increasing image file size because at higher image sizes, WebP gives a better compression ratio that results in smaller WebP files. The results suggest that the webpages can be embedded with WebP format instead of PNG or JPEG to achieve lower power consumption on wearable devices. As an example, converting all webpage images to WebP provides savings of 20% in power consumption and 33% lower webpage load time for [ted.com](http://ted.com). Similar conversion on [m.wikihow.com](http://m.wikihow.com) gives 45% savings in power and 50% lower webpage load time.

### 4.3 Cost of HTTPS

We studied the potential impact of wider adoption of HTTPS by measuring the performance of HTTPS versus HTTP on Glass and compare it to a smartphone. We measured the webpage load time for both HTTP and HTTPS version of the website and calculated power consumption, temperature variation and downloaded network bytes for the duration of the webpage load time. Eighteen out of 50 websites supported both HTTP and HTTPS. However, we could only compare results for 13 websites.

We did a correlation analysis similar to Section 4.1. The result is shown in Figure 7. We find the number of web objects as the common factor among the top three factors for the three performance metrics: relative total power consumption, relative webpage load time, and temperature variation on Glass.

Figure 7 shows the results when websites are binned on the basis of the number of web objects requested from their landing webpage. For the websites with smaller number of web objects (64 or less), Glass webpage load time is 27% higher than smartphone. However, Glass power consumption is 27% lower than smartphone due to the lower rate of power consumption. It is with increased number of web objects (more than 64), we see 69% higher webpage load time and 17% higher power consumption on Glass compared to a smartphone. In general, the extra cost of HTTPS can be attributed to the extra time to maintain and create HTTPS connections. The required extra time needed increases with increasing number of web objects on the webpage and the number of additional servers to contact which worsens the cost of HTTPS on Glass compared to a smartphone. More time also leads to more power consumption and higher temperature on the device.

### 4.4 Transition of Web to Wearables

As noted earlier, we found seven websites: [m.espn.go.com](http://m.espn.go.com), [m.wikipedia.com](http://m.wikipedia.com), [m.wikihow.com](http://m.wikihow.com), [goodreads.com](http://goodreads.com), [telegraph.co.uk](http://telegraph.co.uk), [m.youtube.com](http://m.youtube.com), and [mobile.bloomberg.com](http://mobile.bloomberg.com) that tailored their content specifically for Glass. Overall, we found the general methodology employed by these tailored websites is to deliver less content to Glass than smartphone. In the remainder of this section, we discuss specific features discovered by analyzing tcpdumps.

[m.espn.go.com](http://m.espn.go.com) and [m.wikipedia.com](http://m.wikipedia.com) are optimized by delivering the images to Glass browser according to the device viewport dimensions which results in 50% and 70% reduction in image content download respectively. Considering the number of images on [m.espn.go.com](http://m.espn.go.com) (35) and [m.wikipedia.com](http://m.wikipedia.com) (26), the reduction is considerable. Accessing [m.wikipedia.com](http://m.wikipedia.com) and [m.wikihow.com](http://m.wikihow.com) on Glass fetches less php scripts than smartphone, resulting in savings of (450 kB). [goodreads.com](http://goodreads.com) does not fetch a particular CSS on...
Glass which is required only for smartphone and hence saves 700 kB of traffic. telegraph.co.uk is optimized by not showing ads on Glass and hence not fetching and loading ad related scripts which results in 1 MB of less traffic.

m.youtube.com and mobile.bloomberg.com has a different version of website for Glass and smartphone. Note that by different version, we mean accessing m.youtube.com or mobile.bloomberg.com from Glass fetches a different HTML file for the landing page than on a smartphone. However, the basic methodology of fetching less content applies here as well. Accessing m.youtube.com and mobile.bloomberg.com serves lesser number of web components (images, CSS and JavaScript) to Glass compared to a smartphone version of the website. m.youtube.com serves 50% (700 kB) lesser and mobile.bloomberg.com serves 60% (1.5 MB) lesser content to Glass than smartphone.

5. RECOMMENDATION

On the basis of insights gained from our study, we provide a set of recommendations.

- Reducing web content for wearables: JavaScripts significantly impede the performance of Glass browser in terms of power consumption and webpage load time. We believe that their quantity and complexity can be reduced while serving web content on Glass and similar wearables. The other way to reduce content is by serving less CSS, images, ads and keeping in consideration the display capability of the requesting device.

- Using efficient image formats: WebP image format instead of JPEG or PNG can be used on webpages. This will save power as well as decrease webpage load time.

- Cloud assisted solutions: A way to achieve low cost web experience on wearables is to have a light weight browser rather than a full fledged browser as Glass possess right now. The light weight browser can use cloud based acceleration as done by Opera Mini on smartphones. In cloud acceleration, the scaling of images and execution of JavaScript is done in the cloud and finally the light weight browser displays the webpage. Another way to achieve efficient browsing on a wearable device is to make use of a data compression proxy on the cloud. Proxy can help in reducing network bandwidth, power consumption and webpage load time on the wearable device.

- Using newer protocols: HTTPS has a high impact on the Glass browser performance especially for complex webpages. One way to provide secure communication at lesser cost than HTTPS might be to use newer protocols such as SPDY or the recently finalized HTTP 2.0.

6. CONCLUDING REMARKS

In our study, we find out that in general, the performance on Glass is worse than a smartphone while accessing web content. The primary reason for the performance issues on Glass is because the same content is being delivered to Glass and smartphone regardless of the device type. Wearable is a new type of mobile device with limitations such as smaller form factor and smaller battery than smartphone. The web content delivery ecosystem evolved over time after the advent of smartphones and tablets by switching to efficient protocols such as SPDY, creation of mobile friendly websites, and adoption of techniques such as cloud acceleration. With increasing popularity of wearables, we expect a similar evolution for wearables would lead to a wearable friendly web ecosystem.

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