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The Cost of the “S” in HTTPS

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ABSTRACT

Increased user concern over security and privacy on the Internet has led to widespread adoption of HTTPS, the secure version of HTTP. HTTPS authenticates the communicating end points and provides confidentiality for the ensuing communication. However, as with any security solution, it does not come for free. HTTPS may introduce overhead in terms of infrastructure costs, communication latency, data usage, and energy consumption. Moreover, given the opaqueness of the encrypted communication, any in-network value added services requiring visibility into application layer content, such as caches and virus scanners, become ineffective.

This paper attempts to shed some light on these costs. First, taking advantage of datasets collected from large ISPs, we examine the accelerating adoption of HTTPS over the last three years. Second, we quantify the direct and indirect costs of this evolution. Our results show that, indeed, security does not come for free. This work thus aims to stimulate discussion on technologies that can mitigate the costs of HTTPS while still protecting the user’s privacy.

Categories and Subject Descriptors
C.2.2 [Computer-Communication Networks]: Network Protocols

Keywords
HTTP 2.0; HTTPS; TLS; privacy; security; Web proxies

1. INTRODUCTION

The HyperText Transfer Protocol (HTTP) was first introduced in the early 90s. Since then, the Internet has changed significantly, becoming a vital infrastructure for communication, commerce, education, and information access. HTTPS, the secure version of HTTP, runs HTTP on top of SSL/TLS[1]. While originally geared toward services that require data confidentiality or authentication between end points and provides confidentiality for the ensuing communication, any in-network value added services requiring visibility into application layer content, such as caches and virus scanners, become ineffective.

First, taking advantage of datasets collected from large ISPs, we examine the accelerating adoption of HTTPS over the last three years. Second, we quantify the direct and indirect costs of this evolution. Our results show that, indeed, security does not come for free. This work thus aims to stimulate discussion on technologies that can mitigate the costs of HTTPS while still protecting the user’s privacy.

Figure 1: The HTTPS adoption impact chain.
A common belief is that deploying HTTPS increases infrastructure costs (to accommodate the resulting computational, memory, and network overhead) in addition to the cost of certificates (up to $1,999/year each\(^1\)). Thus, one would expect services to carefully deploy HTTPS only when needed. To test this, we examine recent HTTPS usage trends. We collected per-flow logs from a vantage point monitoring the traffic of about 25,000 residential ADSL customers of a major European residential ISP (“Res-ISP”). The vantage point runs Tstat [7], which implements a classifier supporting both HTTP and TLS identification. For TLS traffic, Tstat parses the ClientHello and ServerHello TLS handshake messages to extract (i) Server Name Indication (SNI), i.e., the hostname to which the client is attempting to connect, and (ii) Subject Common Name (SCN) carried in the server certificate, i.e., the name the server itself presents. Tstat is also able to identify the presence of SPDY in the TLS connections. In the following, we use this rich ISP dataset to characterize the evolution of HTTPS usage. At the time of writing, HTTPS and HTTP combined represent 75% of all TCP traffic (by volume) in Res-ISP.

Fig. 3 reports the evolution of the HTTPS traffic share from April 2012 to September 2014. Both volume and flow shares are shown. The growth of HTTPS adoption is striking, with the HTTPS flow share more than doubling in two years. In September 2014, 44.3% of web connections already use HTTPS.\(^2\) The sharp bump in April 2013 is due to Facebook enabling HTTPS by default for all users [13].

Unsurprisingly, a few optimizations have been proposed to reduce handshake costs. Hardware accelerators, GPU architectures [12], or “rebalancing” the RSA computations [3] can easily boost server performance by a factor of 10. Also, the TLS standard provides a fast negotiation mechanism, shown in Fig. 2 (right). In this case a SessionID is used to retrieve a previously negotiated session key, (i) avoiding the cost of creating a new session key and (ii) reducing the handshake to 1 RTT (2 including the TCP handshake). Note that the adoption of fast negotiation is controlled by the server; as we see in Sec. 4, only some services deploy it.

### 3. HTTPS USAGE TRENDS

SSL/TLS is the standard protocol for providing authenticity and confidentiality on top of TCP connections. Today, it is used to provide a secure version of traditional protocols (e.g., IMAP, SMTP, XMPP, etc.); in particular, the usage of HTTP over TLS is commonly known as HTTPS.

Each TLS connection begins with a handshake between the server and the client. In this handshake, the Public Key Infrastructure (PKI) suite is used to authenticate the server (and sometimes the client) and to generate cryptographic keys to create a secure channel for data transmission.

Fig. 2 (left) sketches the steps in a full TLS negotiation. In this scenario, the client and the server incur different costs. On the server side, the primary cost is computing the session key. This involves complex public key cryptography operations (typically RSA), limiting the number of connections per second the server can support [2, 3, 4]. For clients, the major cost is latency. This depends on (i) server performance, (ii) the distance between client and server since a full negotiation requires 2 RTTs (3 including the TCP handshake), and (iii) the latency to verify the server’s certificate with the PKI (e.g., an OSCP/CRL check).

Curiously, only 5.5% of flows successfully negotiated SPDY, despite 55% of clients offering the option. This highlights
Looking at volume, we see a much slower growth. Intuitively, one would expect that most HTTPS flows carry small, privacy-sensitive objects. We see this until January 2014 when YouTube began delivering video content over HTTPS, clearly increasing the HTTPS volume share. As of September 2014, as much as 50% of YouTube’s aggregate traffic volume is carried over HTTPS.

Fig. 4 further details HTTPS trends with respect to upload volume, download volume, number of hostnames, and number of server IP addresses. We compare the first week of April in 2012, 2013 and 2014 (results are consistent for other weeks). Percentages show the year-to-year increase. The growth of HTTPS is again evident. For instance, HTTPS accounts for 80% of the upload volume in 2014; it was only 45.7% in 2012. This reflects the fact privacy-sensitive information tends to be uploaded using HTTPS more and more. Interestingly, the fraction of data downloaded using HTTPS is smaller than the fraction uploaded. However, YouTube’s shift to HTTPS in 2014 dramatically changed the landscape: HTTPS download volume more than doubled compared to 2013. Fig. 4 also highlights a constant year-by-year increase for both the fraction of hostnames and server IP addresses accessed using TLS. Interestingly, 72% of the TLS hostnames are accessed exclusively over TLS in 2014.

These results clearly show that, despite the perceived costs, services are rapidly deploying HTTPS. This shift is undoubtedly related to the recent attention toward guaranteeing end-users privacy. However, this may also be an indication of increasingly manageable infrastructural costs. This is consistent with the report from the GMail team after their migration of increasingly manageable infrastructural costs. This is especially evident on 3G, where the extra latency is larger than 500 ms for about 90% of websites, and 25% of the pages suffer an increase of at least 1.2 s (i.e., an inflation factor larger than 1.5x). On fiber, the extra latency is smaller; still, for 40% of the pages, HTTPS adds more than 500 ms (1.3x).

**Takeaway:** HTTPS accounts for 50% of all HTTP connections and is no longer used solely for small objects, suggesting that the cost of deployment is justifiable and manageable for many services.
TLS Handshake delay cost: Webpage load time has been an active area of research [8, 5, 15, 11]: understanding the exact cause(s) of the inflation noted above is quite complex and out of scope for this work. However, it is still interesting to understand whether the overall page latency is primarily affected by network latency or by protocol overhead. To better understand this, we modified Tstat to extract the (i) duration and (ii) number of bytes of each TLS handshake from a one-hour pcap trace collected on April 3rd 2014 from Res-ISP. About 1 million TLS flows are present.

Fig. 7 (left) shows a scatter plot of the TLS handshake duration with respect to the minimum external RTT (i.e., the RTT between the vantage point and the remote server\(^6\)). The external RTT is reasonably representative of the distance to the remote server. For this analysis we selected popular services as representative cases (we classify based on the Server Name Indication in the ClientHello).

First, all services exhibit vertical clusters of points, which likely reflect the different data centers offering that service. For instance, when the external RTT is larger than 100 ms, the server is outside Europe. More interestingly, no matter how close the servers are, all clusters contain samples with very high TLS handshake duration, i.e., up to several seconds. To better capture this effect, Fig. 7 (center) reports the CDF of the TLS handshake duration for individual services and for the traffic aggregate (black dotted line). Google services (which are also the closest) exhibit the smallest TLS negotiation delay, though 10% of measurements are more than 300 ms. Since a full TLS handshake requires at least 2 RTT (1 RTT in case of SessionID reuse), services handled by U.S. servers (e.g., Hotmail, Twitter, Amazon S3) experience huge extra costs. For instance, for Twitter, negotiation takes over 300 ms for more than 50% of the HTTPS connections. In general, 5% of requests experience a handshake at least 10 times longer than the RTT. This might be due to client or server overhead, network congestion, or a slow OCSP check.

Looking closer, we find that 4% of clients experience at least one connection with a TLS handshake duration higher than 300 ms. For such connections, 50% (75%) have an external RTT (i.e., the RTT between the vantage point and the end-user device) of 51 ms (97 ms). The same holds true with less conservative thresholds (e.g., 1 second). This demonstrates that even clients with good network connectivity can still significantly suffer from TLS handshake overhead. TLS fast negotiation can help to reduce the handshake latency, but we find this being used in only 30% of the connections. We speculate this represents a lower bound, but, unfortunately, based on available data, we cannot assess the achievable upper bound obtained from a wider adoption of TLS fast negotiation.

**Takeaway:** The extra latency introduced by HTTPS is not negligible, especially in a world where one second could cost 1.6 billion in sales.\(^7\)

5. DATA USAGE

HTTPS also impacts the volume of data consumed due to (i) the size TLS handshake and (ii) the inability to utilize in-network caches and compression proxies.

TLS Handshake Data Cost: The impact of the TLS handshake overhead depends on how much use the connection sees; the more data transferred, the lower the relative cost of the negotiation packets. Fig. 7 (right) reports the Complementary Cumulative Distribution Function (CCDF) of the ratio between TLS handshake size and total bytes carried in the TCP connection. Results refer to a peak hour in April 2014 for the Res-ISP dataset and are consistent with other time periods. We see that many TLS connections are not heavily used. In fact, for 50% of them, the handshake represents more than 42% of the total data exchanged. However, some services, like those running on Amazon S3, do actually use connections efficiently, reducing the impact of the negotiation cost. Some services also try to mask negotiation latency by “pre-opening” connections before they actually need to send data. In this case, the negotiation overhead is 100% if the connection is never used. This is captured in the rightmost part of Fig. 7 (right), which also highlights how this optimization is heavily used by Google, Amazon S3, and Twitter, but is not by Hotmail and Apple.

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\(^6\)Tstat extracts RTT per-flow statistics monitoring the time elapsed between TCP data segments and the corresponding TCP ACK.

\(^7\)http://www.fastcompany.com/1825005/how-one-second-could-cost-amazon-16-billion-sales
services. Despite all this variability, the average TLS negotiation overhead amounts to 5% of the total volume in this dataset.

**In-Network Proxies:** HTTPS prevents in-network content optimizations, like proxies that perform compression and caching. To evaluate the impact of this loss, we analyze logs from two production HTTP proxies for mobile networks: **Transp-Proxy** and **OptIn-Proxy**. **Transp-Proxy** refers to a transparent proxy in a major European mobile carrier serving more than 20 million subscribers. **OptIn-Proxy**, on the other hand, is an explicit proxy serving 2000 mobile subscribers daily in a major European country. For **Transp-Proxy**, we analyze the past two years of traffic and for **OptIn-Proxy** we consider a week-long trace from May 2014.

**Caching (ISP Savings):** An ISP can save upstream bandwidth by serving static content from its own transparent cache. In the **Transp-Proxy** dataset, the average cache hit ratio over the past two years was 14.9% (15.6% of the total data volume), amounting to savings of 2 TB per day for a single proxy instance serving 3 million subscribers. For **OptIn-Proxy**, we see daily savings of 1.3 GB, which, if scaled up to the **Transp-Proxy** population, matches the observed **Transp-Proxy** savings.

We also witnessed a decrease in cache efficiency: the cache hit ratio of **Transp-Proxy** dropped from 16.8% two years ago to 13.2% in June 2014. Based on our analysis, it is not easy to conclude how much of the decreasing effectiveness of caching is related to the adoption of HTTPS and how much is caused by the increased personalization of web traffic. Either way, savings of this size can be still significant to network operators; such savings will be totally eliminated if content delivery moves entirely to HTTPS.

**Compression (Users Savings):** Before returning content to users, web proxies typically apply lossless (e.g., gzip) compression to objects and, in more aggressive settings, even scale or re-encode images. This functionality is particularly helpful in cellular networks where the capacity is limited and where users often have restrictive data allowances. The **Transp-Proxy** trace shows a compression ratio of 28.5% (i.e., the last-mile of the network and the users save one-third of the original data size). In terms of average volume, this amounts to only 2.1 MB per user per day (on average a mobile user downloads less than 10 MB per day). For heavy users, though, this may translate to significant savings (e.g., more than 300 MB per month).

**Takeaway:** Most users are unlikely to notice significant jumps in data usage due to loss of compression, but ISPs stand to see a large increase in upstream traffic due to loss of caching.

Figure 8: Energy consumption on 3G (left) & Wi-Fi (right).

6. **BATTERY LIFE**

HTTPS has the potential to negatively impact battery life (particularly on mobile devices) due to (i) the extra CPU time required for the cryptographic operations and (ii) increased radio uptime due to longer downloads.

**Synthetic Content:** To measure the raw energy overhead of HTTPS, we instrumented a Galaxy S II with a power meter that samples the current drawn by the phone every 200 µs. We used the test phone to download synthetic objects over 3G and Wi-Fi (i.e., an access point connected to a fiber link). Objects range in size from 1 kB to 1 MB and are hosted on a web server under our control. Objects are downloaded 100 times each over HTTP and HTTPS using curl (compiled for Android). We configured the server to deliver traffic avoiding any proxy cache along the path. During our tests, the screen was on at its minimum brightness.

Fig. 8 shows both average time (right y-axis) and energy (left y-axis) to complete each download. It is immediately clear that energy consumption is strongly correlated to download time; this is not surprising, as leaving the radio powered up is costly. (We also see a slight overhead for large objects over HTTPS on Wi-Fi but not on 3G, but we were unable to precisely determine the cause. The difference is less than one standard deviation.) The key takeaway here is, download time aside, we do not see a noticeable overhead due to cryptographic operations.

**Real Content:** We complement the previous analysis by loading real content. We mirror the CNN homepage on our controlled web server and download it 50 times using Chrome for Android over HTTP and HTTPS (enforcing 20 seconds of wait between consecutive downloads). Results are listed in Table 1 (numbers presented are cumulative for all 50 loads). As in the previous benchmark, HTTPS tests do not show an appreciable increase in energy costs.

In a second experiment, we play four 5- to 12-minute YouTube videos. Since the YouTube app does not deliver

The 3G carrier used in the experiment runs transparent proxies acting on traffic to port 80. By configuring the web server to listen on a different port, we bypass the cache.

Table 1: Energy consumed loading CNN homepage.

<table>
<thead>
<tr>
<th></th>
<th>3G</th>
<th>Wi-Fi</th>
<th>3G</th>
<th>Wi-Fi</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTTP</td>
<td>210.8</td>
<td>175.7</td>
<td>633</td>
<td>520</td>
</tr>
<tr>
<td>HTTPS</td>
<td>217.7</td>
<td>178.0</td>
<td>653</td>
<td>531</td>
</tr>
</tbody>
</table>

The 3G carrier used in the experiment runs transparent proxies acting on traffic to port 80. By configuring the web server to listen on a different port, we bypass the cache.
video content over HTTPS for mobile devices (nor does the YouTube mobile site), we first force the phone to load the desktop version of the YouTube portal. Over Wi-Fi, there was no difference; on 3G, on the other hand, our network's Web proxy significantly impacted the HTTP results. For two videos, playback over HTTP (with proxy) consumes nearly 22% less energy than over HTTPS (without proxy); for the other two, 10%-20% more (Fig. 9 left).

The differences are caused by two distinct proxy behaviors. First, the proxy throttles the download rate (Fig. 9 right) to reduce congestion and avoid wasting bandwidth if the user abandons the video. Without the proxy (HTTPS), the whole video loads immediately and the radio sleeps while it plays. With the proxy (HTTP), the download is slow and steady, lasting the duration of the video. Without the opportunity to sleep, playback over HTTP consumes more energy. Second, the proxy injects JavaScript into the pages it returns, which, among other things, rewrites the URLs (and increases the opportunity to sleep, playback over HTTP consumes more energy). Similarly, rewrites the URLs may still be detectable through statistical analysis of the complete URL being accessed.

Takeaway: Though difficult to quantify, the loss of in-network services is potentially substantial; some of that functionality could be equally well performed on the client, while some may require a total rethink, like DPI-based Intrusion Prevention Systems (IPSes).

8. CONCLUSION

Motivated by increased awareness of online privacy, the use of HTTPS has increased in recent years. Our measurements reveal a striking ongoing technology shift, indirectly suggesting that the infrastructural cost of HTTPS is decreasing. However, HTTPS can add direct and noticeable protocol-related performance costs, e.g., significantly increasing latency, critical in mobile networks.

More interesting, though more difficult to fully understand, are the indirect consequences of the HTTPS: most in-network services simply cannot function on encrypted data. For example, we see that the loss of caching could cost providers an extra 2 TB of upstream data per day and could mean increases in energy consumption upwards of 30% for end users in certain cases. Moreover, many other value-added services, like parental controls or virus scanning, are similarly affected, though the extent of the impact of these “lost opportunities” is not clear.

What is clear is this: the “S” is here to stay, and the network community needs to work to mitigate the negative repercussions of ubiquitous encryption. To this end, we see two parallel avenues of future work: first, low-level protocol enhancements to shrink the performance gap, like Google’s ongoing efforts to achieve “0-RTT” handshakes. Second, to restore in-network middlebox functionality to HTTPS sessions, we expect to see trusted proxies [9] become an important part of the Internet ecosystem.

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