

Privacy and Security Issues in BAT Web Browsers

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Abstract

In this position paper, we summarize our technical analysis of the security and privacy vulnerabilities in three web browsers developed by China’s three biggest web companies: UC Browser, QQ Browser and Baidu Browser; developed by UCWeb (owned by Alibaba), Tencent and Baidu, respectively. We found them to consistently contain sensitive data leaks and remote code execution vulnerabilities in their update processes. Despite the massive user bases of these browsers, particularly in China, there has been limited attention paid to the applications by the information security research community. This lack of attention is problematic, as it is known that the insecure transmission of personal user data by UC Browser has been used by the intelligence community to perform surveillance. We conclude by evaluating explanations for why this class of apps has such uniform security and privacy issues, and recommend researchers better engage software development companies in developing and newly industrialized economies.

1 Introduction

Browsers are ubiquitous across all platforms and hardware types, and so the variety of browsers available—particularly on mobile devices—is wide. Although most browsers contain similar features, the manner in which they collect and use personal user data may vary widely. This is concerning, as web browsers are used to transmit sensitive user data across a broad variety of media and devices.

Nowhere is the market for third-party browsers more competitive than in China, particularly amongst the country’s “Big 3” tech giants. These companies—Baidu, Alibaba, and Tencent, collectively known as “BAT”—operate in China’s highly competitive and dynamic market, where the absence of companies dominant in western markets have opened up opportunities in the largest Internet market in the world. The three companies have each

released a free browser: Baidu Browser, UC Browser (developed by Alibaba-owned UCWeb) and QQ Browser. All based on the Chromium platform, these browsers offer a set of features not generally offered by browsers like Chrome and Safari, including integration with each company’s product suite, built-in torrent support, mouse gestures, and compression features aimed at reducing mobile data usage.

The three applications have earned millions of users, particularly in China and throughout Asia. QQ Browser and UC Browser are amongst the top 5 most used browsers in China, while Baidu Browser falls outside of the top ten [22]. UC Browser is the clear leader of the three internationally, and is by some estimates the second most popular mobile web browser globally, after Chrome [21]. However, despite the significant user bases of these applications, as well as the dominant market positions of their parent companies, there is limited research into the privacy and security practices they employ. Our research demonstrates that this lack of attention has been problematic.

In this paper, we describe the results of detailed security analyses of the three browsers, including what user data is collected, stored and transmitted by the browsers, what methods are used to secure these transmissions, and whether the applications exhibit any vulnerabilities that could compromise the privacy and security of user data. In addition, we discuss our responsible disclosure of these issues to the three companies.

Our main findings are as follows:

Each browser collects and transmits significant amounts of personal user data. All three browsers collected and transmitted a large number of personal data points, including a variety of hardware identifiers, locational data, and user web browsing history.

Each browser uses insecure methods to transmit this data. Each application transmitted user data through insecure means, ranging from using easily decrypted symmetric encryption methods to sending user data with-

out any encryption.

Each browser has vulnerabilities in the software update process. At least one version of each browser performed software updates in a manner which left it vulnerable to an attacker executing arbitrary code.

The browsers did not use established, industry-standard methods of securing data transmissions. The methods employed to secure the transmission of personal data, where used at all, did not use well-tested implementations of industry-standard protocols (such as OpenSSL) and were often home grown.

These results show that these privacy and security concerns are not isolated to any one company, and reflect broader issues with development and security of applications popular in China. As a result, we argue that security researchers should focus more attention on these applications, which are used by hundreds of millions of people without significant external scrutiny.

2 Background and Related Work

The application’s developers are the three biggest technology companies in China, collectively dominating the online search, social media and e-commerce fields [27]. Baidu’s search engine dominates the Chinese market in the absence of Google, having captured 70% market share and recording over 660 million mobile monthly search users in March 2016 [2]. Tencent operates two of the world’s largest communications platforms, with QQ Instant Messenger having 853 million users and mobile messenger WeChat/Weixin having 697 million active monthly users [24]. Alibaba operates a number of the largest e-commerce sites in China, including Taobao and TMall, which have over 367 million active shoppers [7]. Combined, the companies operate five of China’s top seven most visited websites [1].

Definitive estimates of the market share of these three browsers are difficult to obtain. Of the three browsers examined, UC Browser is by far the most popular, ranking as the most popular mobile browser in China, India and Indonesia [20], and is by some estimates the second most popular mobile browser in the world [21]. While some estimates report QQ and Baidu Browsers as the second and third most popular mobile browsers in China [4], others put their combined market share at less than 10% [21].

The insecure transmission of personal user data and potential for the execution of arbitrary code in these applications are not merely hypothetical concerns. Documents leaked by Edward Snowden show that western intelligence agencies had, as far back as 2012, identified information leakage vulnerabilities in UC Browser and successfully used them to design an XKeyscore plugin to surveil users of the application [6].

| Browser | O/S (Edition) | Version |
|---------------|---------------|----------------|
| Baidu Browser | Windows (C) | 7.6.100.2089 |
| Baidu Browser | Windows (I) | 43.22.1000.452 |
| Baidu Browser | Android (C) | 6.2.18.0 |
| Baidu Browser | Android (I) | 5.1.0.1 |
| QQ Browser | Windows | 9.2.5478 |
| QQ Browser | Android | 6.3.0.1920 |
| UC Browser | Windows (C) | 5.5.10106.5 |
| UC Browser | Windows (I) | 5.5.9936.1231 |
| UC Browser | Android (C) | 10.9.0.703 |
| UC Browser | Android (C) | 7.9.3.103 |
| UC Browser | Android (I) | 10.9.0.731 |

Table 1: Application versions analyzed; (I) refers to international edition, (C) refers to Chinese-language edition

There is some prior research on both the leakage of personal data as well as the execution of malicious code in the three browsers. Wu and Chang [25] examined 115 Android web browsers, finding that more than half, including versions of Baidu and UC Browsers were vulnerable to attackers gaining access to personal user data stored on the device. Similarly, Wu and Chang [26] find that Android versions of QQ and Baidu Browsers are vulnerable to attacks which could compromise private user data. Ma [14] finds that vulnerabilities with UC Browser’s integration of Alibaba’s search engine Shenma caused the active user sessions for a number of popular Chinese social media sites to be cached by the search engine, allowing anyone to gain access to user accounts. Liu and Wang [13] use automated methods to identify the leakage of personal data in popular Chinese Android apps, confirming Dalek *et al.*’s earlier findings [5] about leakage in UC Browser via a hard-coded AES key.

3 Technical Analysis

Our analysis includes both Android and Windows versions of Baidu Browser, QQ Browser, and UC Browser. In total, we examined 11 different versions, as summarized in Table 1.

We found that each version of the browsers we analyzed collected personally identifying information such as hardware serial numbers. Many also transmit location information such as GPS coordinates or nearby WiFi networks, and most track the full URLs of pages viewed, even if the pages were originally retrieved via HTTPS.

We also found that each version of the browser transmitted this data via *easily decryptable* encryption. By this we do not mean that the encryption algorithm used is itself insecure (although in many cases it is). Instead we mean that the encryption is entirely symmetric and uses hard-coded keys. Since the algorithms are not asymmet-

| Browser (O/S) | PII | Location | Activity |
|-------------------|-----|----------|----------|
| Baidu Browser (W) | ✓ | | ✓ |
| Baidu Browser (A) | ✓ | ✓ | ✓ |
| QQ Browser (W) | ✓ | | ✓ |
| QQ Browser (A) | ✓ | ✓ | ✓ |
| UC Browser (W) | ✓ | | ✓ |
| UC Browser (A) | ✓ | | ✓ |

Table 2: Whether the latest version of each Chinese-language browser was found to leak a user’s personally identifiable information, location, or browser activity; (W) refers to Windows version, (A) refers to Android version

| Data point | Type | Encryption |
|--------------------------|----------|--------------------|
| MAC address | PII | Easily decryptable |
| Hard drive serial number | PII | Easily decryptable |
| Search terms | Activity | Not encrypted |
| Full HTTP(S) URLs | Activity | Easily decryptable |
| HTML page titles | Activity | Easily decryptable |

Table 3: Data leaks in version 7.6.100.2089 of Chinese-language Baidu Browser for Windows

ric, anyone analyzing the encryption algorithm and hard-coded keys used by the browsers can decrypt what they encrypt. In each case, we confirmed this by writing code ourselves to decrypt each browser’s encrypted traffic. We summarize each browser’s insecure data leakage in Table 2.

Finally, we found that most of the browsers have vulnerabilities in their self-update processes allowing someone from a privileged point on the network to inject traffic that could cause the browser to run arbitrary code.

In the remainder of this section, we summarize our analysis of the Chinese-language editions of Baidu Browser, QQ Browser, and UC Browser, respectively. (Our results are explained in more detail in [10, 11, 17].)

3.1 Analysis of Baidu Browser

We found that **Baidu Browser for Windows version 7.6.100.2089** leaks sensitive data over the network as summarized in Table 3. The easily decryptable data points are only protected by a symmetric block cipher. It is a modified version of the TEA algorithm we call *MTEA*. The block cipher mode used is a version of CBC modified to perform an additional XOR operation between blocks that we call *MCBC*.

We also found that the browser does not use asymmetric cryptography to verify software updates. Update metadata is transmitted via the symmetric

| Data point | Type | Encryption |
|-----------------------------|----------|--------------------|
| IMEI | PII | Easily decryptable |
| GPS coordinates | Location | Not encrypted |
| In-range WIFI access points | Location | Easily decryptable |
| Search terms | Activity | Not encrypted |
| Full HTTP(S) URLs | Activity | Not encrypted |

Table 4: Data leaks in version 6.2.18.0 of Chinese-language Baidu Browser for Android

MCBC+MTEA algorithm, and the downloaded binary is only verified using MD5 hashes, not digital signatures. By performing a man-in-the-middle attack on the browser when it is checking for updates, we were able to download and run an arbitrary executable.

We found that **Baidu Browser for Android version 6.2.18.0** leaks sensitive data over the network as summarized in Table 4. The easily decryptable data points were found to be encrypted using a variety of symmetric algorithms. The IMEI is sent insecurely in multiple places, in one instance encrypted with a custom “homebrew” algorithm encrypting with a 32-bit XOR mask, bit rotations, and a nonstandard base64 alphabet. In another instance, it is encrypted using only a hard-coded 5-byte ASCII RC4 key ("HR2ER").

We also found the browser encrypted data using a hard-coded ASCII AES key ("h9YLQoINGWYOBYYk") containing the IMEI number, GPS coordinates, and in-range WiFi access points. We identified this code as belonging not to Baidu Browser proper but to Baidu’s Mobile Tongji SDK, which is used to perform analytics. Using data from Lookout, a mobile security company, we found that this SDK is not only used by other Baidu products but also thousands of third party Google Play Store apps. The most popular of these applications was the ES File Explorer File Manager (com.estrongs.android.pop), which the Google Play Store reports to have between 100 to 500 million installs. (Since the Google Play Store is inaccessible in China, this number is unlikely to account for most users in mainland China.)

We found that the Android version’s update process was also vulnerable to man-in-the-middle attacks, as its update is protected with only an MD5 hash. By injecting network traffic, we were able to attack the browser and cause it to prompt the user to install an arbitrary app.

3.2 Analysis of QQ Browser

We found that **QQ Browser for Windows version 9.2.5478** leaks sensitive data over the network as summarized in Table 5. The easily decryptable data points were

| Data point | Type | Encryption |
|----------------------------------|----------|--------------------|
| “Hardware fingerprint” | PII | Not encrypted |
| Machine hostname | PII | Easily decryptable |
| Gateway MAC address | PII | Easily decryptable |
| Hard drive serial number | PII | Easily decryptable |
| Windows user security identifier | PII | Easily decryptable |
| Search terms | Activity | Not encrypted |
| Full HTTP(S) URLs | Activity | Not encrypted |

Table 5: Data leaks in version 9.2.5478 of QQ Browser for Windows; we call the “hardware fingerprint” QQ Browser’s hash of the machine’s MAC address and hard drive serial, model and controller version numbers.

encrypted using a variety of encryption algorithms with hard-coded keys, including DES+ECB and 3DES+ECB. Most sensitive data, however, was encrypted using the same nonstandard MCBC+MTEA algorithm as in Baidu Browser. It is unclear why both Baidu and QQ browsers would use the same nonstandard encryption to encrypt sensitive data.

We developed proof-of-concept exploits against two vulnerabilities that we found in the browser’s update process. The first vulnerability leverages the fact that verifying digital signatures on downloaded executables is itself insufficient for securing software updates [8]. Although the browser verifies that the new executable is signed by Tencent, it does not verify that the executable represents the same product or a newer version of it. By performing a man-in-the-middle attack, we were able to have the browser download and execute an older web installer for QQ Browser that we found to perform no digital signature verification. The web installer can then be attacked to download and execute an arbitrary executable.

The second vulnerability is a directory traversal attack in QQ’s update process. In retrieving the URL of the executable to download, the browser also receives the name of the file to save the executable as. This file name is not protected by any asymmetric cryptography and is vulnerable to directory traversal. By performing a man-in-the-middle attack and using the path `../../../../../../../../../../../../programfiles/tencent/qqbrowser/qqbrowser.exe` as the file name we were able to overwrite QQ Browser with an arbitrary executable.

We found that **QQ Browser for Android version 6.3.0.1920** leaks sensitive data over the network as summarized in Table 6. The browser encrypted sensitive data using RSA-AES, an asymmetric algorithm; however, due

| Data point | Type | Encryption |
|-----------------------------|----------|--------------------|
| IMEI | PII | Easily decryptable |
| IMSI | PII | Easily decryptable |
| Android ID | PII | Easily decryptable |
| QQ username | PII | Easily decryptable |
| WIFI MAC address | PII | Easily decryptable |
| In-range WIFI access points | Location | Easily decryptable |
| Active WIFI access point | Location | Easily decryptable |
| Search terms | Activity | Not encrypted |
| Full HTTP(S) URLs | Activity | Not encrypted |

Table 6: Data leaks in version 6.3.0.1920 of QQ Browser for Android

| Data point | Type | Encryption |
|----------------------------------|----------|--------------------|
| Hard drive serial number | PII | Easily decryptable |
| Base board serial number | PII | Easily decryptable |
| File system volume serial number | PII | Easily decryptable |
| Full HTTP(S) URLs | Activity | Not encrypted |

Table 7: Data leaks in version 5.5.10106.5 of Chinese-language UC Browser for Windows

to the RSA key length being only 128 bits, the algorithm is still easily decryptable. Using Wolfram Alpha, in less than one second we factored the RSA public key’s modulus (245406417573740884710047745869965023463) into the following prime factors:

$$14119218591450688427 \times 17381019776996486069$$

The randomly generated AES session key, although also 128 bits, is guaranteed to always be less than the 128-bit RSA modulus because the AES key is not chosen from the entire 128-bit keyspace. Instead, the key is uniformly chosen from a space less than 2^{53} in size.

The software update process in this browser is vulnerable to an attack analogous to the one we describe against Baidu Browser for Android.

3.3 Analysis of UC Browser

We found that **UC Browser for Windows version 5.5.10106.5** leaks sensitive data over the network as summarized in Table 7. The easily decryptable data in this browser is protected only by “homebrew” algorithms based on XOR masks using hard-coded keys.

| Data point | Type | Encryption |
|-------------------|----------|--------------------|
| IMEI | PII | Easily decryptable |
| IMSI | PII | Easily decryptable |
| Search terms | Activity | Not encrypted |
| Full HTTP(S) URLs | Activity | Easily decryptable |

Table 8: Data leaks in version 10.9.0.703 of Chinese-language UC Browser for Android

The self updater in this process uses a complex updating scheme designed to efficiently patch the software seeking to minimize the number of bytes downloaded. However, once the scheme is understood, it ultimately is vulnerable to an attack analogous to the one we describe against Baidu Browser for Windows.

We found that **UC Browser for Android version 10.9.0.703** leaks sensitive data over the network as summarized in Table 8. Like the Windows version, the easily decryptable data in this browser is protected only by “homebrew” algorithms based on XOR masks using hard-coded keys. Dalek *et al.*’s report [5] studied version 10.2.1.161 and revealed data leaks by means of a hard-coded AES key, but we found that those leaks had since been fixed.

We also analyzed version 7.9.3.103 of UC Browser for Android released in 2011. We analyzed this version because intelligence agency slides disclosed by Edward Snowden detail an XKeyscore plugin designed to exploit UC Browser data leaks in this version [23]. We did not find the leaks revealed in Dalek *et al.*’s report [5] in this version of the browser, suggesting that they were not the ones used to build the XKeyscore plugin. However, many of the data leaks we found in 10.9.0.703 were also present in 7.9.3.103. These leaks also leak the same data as shown in the slides, suggesting that the vulnerabilities we found in the latest version of the browser are likely the same leaks exploited by the XKeyscore plugin since 2012.

Although the latest version does perform digital signature verification on downloaded APK files, we found that 7.9.3.103 did not, creating a vulnerability in the update process analogous to the one we report in Baidu and QQ browsers for Android. The intelligence agency slides report finding vendor update servers and having the capability to push “malware” to victims’ devices. This is consistent with the man-in-the-middle vulnerability that we found in the 7.9.3.103 version’s update process. Software updates had previously only been speculated to be exploited by state actors to inject malware [8].

3.4 International editions

In addition to Chinese language versions, Baidu Browser and UC Browser are also available in international editions. We found that these versions generally had similar classes of vulnerabilities. We detail these in [10, 11, 17].

4 Responsible Disclosure

We notified all three companies of the issues we identified in their respective browsers, and committed to delay publication of our results for 45 days. We continued our correspondence with all three companies following the initial disclosure in order to further discuss our concerns and their proposed fixes. Following our notification, all three companies released updated versions of their browsers, which our analyses [5, 10, 11, 17] showed addressed some, but not all, of the identified security concerns.

5 Discussion and Conclusion

In this section we discuss some possible reasons the three applications have similar problems, and conclude by arguing that security researchers should focus more on applications of this type.

As Section 3 has shown, all three browsers collected and transmitted user data in similar ways. Such commonalities across these applications may reflect an underlying set of causes.

These applications are developed by companies operating in China’s burgeoning, highly competitive tech market. Each company is attempting to stake out ground across a diverse range of products, from search engines to online shopping to social networking. They each face strong market pressures to release new products and introduce new features quickly, which may limit their ability to thoroughly consider the security and privacy implications. Combined with the lack of external auditing, there appears to be few incentives for these companies to adopt more diligent security practices.

Market pressures also serve to motivate companies to increase their collection of personal data, pressures which are not unique to web browsers or China-based companies. All three of these web browsers are pieces in their respective companies’ larger ecosystems. Free web browsers serve as a vehicle to direct customers towards revenue generating services and help integrate users into a company’s product suite, all while collecting personal user data to more efficiently model user behavior and deliver more targeted advertising. The overzealous collection of personal user data, particularly by mobile apps, is well discussed [18].

Further, all three companies are aggressively pursuing mergers and acquisitions to expand their reach and service offerings to users, in excess of USD\$75 billion between the three since 2013 [16]. Such expansion encourages companies to integrate new products and features into existing applications, potentially expanding the types and quantity of user data that is collected and shared. Initial research into UC Browser showed that geolocation data was collected from users for use in mapping functionality developed by AutoNavi, a company purchased by Alibaba in 2014 [5].

Other market conditions faced by these companies also contribute to the introduction of vulnerabilities. The uniform lack of access to the Google Play Store in China prevents Android developers from using this channel for software updates. As a result, developers are forced to implement their own update mechanisms, which can introduce new vectors for compromise as we discuss in Section 3 and is discussed in [8].

The highly constrained environment in which Chinese technology companies operate may also influence the treatment of user data. The obligations Chinese companies face to monitor and censor content shared by their services have been widely discussed [15, 9, 12]. The role that such requirements may have played in the collection of additional user data is a question for future research. However, several recent legislative and regulatory developments may have had an impact on these companies' practices. Anti-terrorism legislation which came into effect in late 2015 contained provisions requiring technology companies to assist security agencies (including through the decryption of communications) with the investigation and prevention of terrorist activities [19]. China's Ministry of Public Security was reportedly planning to establish "network security offices", staffed by police officers, inside the offices of major Internet companies [3].

Our experience in providing notifications of these vulnerabilities also varied across companies. Of the three, only Tencent had a dedicated website for submitting security notifications; we had to rely upon personal contacts to identify suitable representatives for notification at the other two companies. Further, while all three companies did issue fixes in response to our notifications, these fixes did not address all the identified problems. The fact that we found multiple similar vulnerabilities in UC Browser after those reported in [5] suggests that UC took no approach to lastingly prevent these data leaks. This demonstrates the "whack-a-mole" nature of disclosing such issues. Unless the companies involved adopt a more systematic approach to ensuring the secure collection and transmission of user data, the efforts of security researchers will remain piecemeal.

The enormous growth in users of these applications,

combined with both the highly dynamic application development ecosystem and growing government regulatory pressures around security and antiterrorism warrants the attention of the security community. The risks users face from their unwittingly shared personal data are not hypothetical, as the Snowden disclosures have demonstrated. As we surround ourselves by ever-more deeply embedded digital devices and applications, which, in turn, are often the object of state controls, it is imperative that researchers closely investigate these applications to protect user privacy and security.

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