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Privacy as a proxy for *Green Web browsing*: Methodology and experimentation

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ABSTRACT

Nowadays, users' privacy on the Internet is highly at risk, due to the monetization by advertising companies that support many of the so-called "free" services such as searching or social networking. In fact, several mechanisms are used to monitor users and build detailed profiles to tailor behavioral advertising. Given the increasing use of mobile devices and the increasing revenues from behavioral advertising, large advertising companies are present in this market as well.

The increasing use of mobile devices for interacting with the Web and using mobile applications has been also drawing attention to their energy consumption. Several studies have addressed this issue from different point of views, i.e., hardware, software, as well as by analyzing the energy drained by different mobile applications.

Our goal in this work is to measure the effectiveness of a methodology that exploits a hardware-based instrumentation to study whether privacy-preserving mechanisms are also able to efficiently reduce communication and computation overhead and, thus, save the battery life of mobile phones with the overall aim of a more sustainable Internet.

1. Introduction

According to a recent Pew Research Survey [1] roughly three-quarters of Americans (77%) now own a smartphone, while recent statistics from comScore [2] show that mobile, now, represents almost 7 in 10 digital media minutes, smartphone apps alone account for half of all digital time spent and nearly one in eight U.S. Internet users are now mobile-only, with 18–24 year-old women the highest skewing for this behavior. Google company [3] adds that "*more Google searches take place on mobile devices than on computers in 10 countries including the US and Japan*", with mobile queries that include mobile browser-based searches and those coming from Google's mobile search apps. According to further recent statistics [4], monthly global mobile data traffic will surpass 24.3 exabytes by 2019, where smartphones will reach three-quarters of mobile data traffic by the same year.

The increasing popularity of mobile devices is certainly due to their affordability, computational power and to the always growing number and variety of services and useful applications. To wit, the number of free and charged-for downloads from mobile application stores worldwide increased from 17.7 billion in 2011 to over 200 billion in 2017 [5].

The main drawback of mobile popularity is their energy footprint, as many applications, (such as video-on-demand, mobile gaming, location-aware applications and general content for entertainment) require high throughput network connectivity which needs continuous data network transmission over WiFi or 3G networks with a significant impact on battery consumption [6,7].

We want to emphasize that although the annual electricity requirements of one charging smartphone is negligible, their aggregated impact cannot be ignored. If we consider that the number of smartphone owners will surpass 6 billion by 2020 [8] and that the unit energy consumption (UEC) is about 4.5kWh/year [9], their collective electricity consumption does, indeed, represents a critical issue. Interestingly enough, the energy issue is often overlooked by programmers, as a survey showed [10] that programmers have

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limited knowledge of energy efficiency, they lack knowledge of the best practices to reduce software energy consumption, and are even unsure about how software consumes energy.

Therefore, the study of new mechanisms to increase battery life of cell phones to build a more sustainable Internet becomes increasingly important and represents the overall objective we want to achieve in this work.

As mobile devices become more prevalent and our Web presence expands for a variety of daily activities, from business to social, the market for mobile ads will grow at the same pace. Large business companies (aggregators, analytics service, ad-server and so on) continuously monitor users' behaviors, actions and habits to catch consumers' attention and to provide them targeted advertising. The practice of tracking individuals' online activities is not a dangerous activity *per se*, and, although increases the effectiveness of the marketers' campaigns as well as their revenues [11], it has also strong implications for both the users and the network. First, it undermines **users' privacy** since their data, collected and aggregated, could be used by 3rd-party entities for secondary activities, instead of for what the behavioral advertising has been envisioned for; secondly, mobile ad traffic is responsible for important network and, therefore, **energy overhead** [12]. As an example, a study [13] shows that an astonishing 65–75% of the energy consumed in a gaming app (Angry Birds) on Android devices is spent by 3rd-party advertising modules.

Users' privacy is heavily at risk: in fact, behavioral advertising heavily relies on the use of valuable information that could lead to an accurate reconstruction of users' interests profiles, when leaked to 3rd-party entities [14–16]. But the real main risk is about the final use of pseudo-anonymous data, that linked with personally identifiable information, may be potentially used for secondary activities, such as identity theft, social engineering attacks, online and physical stalking and so on [17].

In order for downloading Web pages and associated behavioral advertising on mobile devices to be as effective as desktop environments, more computation/communication and thus more energy will be required. Since loading Web resources contributes most of the browser delay [18], we seek to investigate if filtering advertisements and unwanted content, and blocking tracking activities from advertising companies, can provide new opportunities for power optimization in addition to increasing privacy protection.

Specifically, we want to study potential energy savings resulting via *mNoTrace*, a Privacy-Enhancing Technology (PET) implemented as Mozilla Firefox add-on. After a brief description of the tool, we study whether it can help users in limiting the diffusion of their personal and sensitive information, and *en passant* reduce communication and computation overhead and, thus, battery consumption. This alternative use of PETs, while enabling users to have safer and sustainable access to Internet, could also represent a good stimulus for some people, that even if generally worried about privacy, are often simply lazy in protecting themselves [19,20]. The main contributions of our paper are as follows.

- Measure the effectiveness of a methodology, presented in a earlier work [21], on extensive datasets: (1) popular Web sites (root Web pages without following embedded links); (2) a large set of popular Websites in a row; (3) a real browsing session (with users' actions) performed on different communication networks; (4) a set of topic-oriented Websites in order to mimic user's profiles and therefore study how users' habits impact on energy consumption.
- Measure the effectiveness (i.e., filtering capabilities) and the efficiency (i.e., energy consumption) of *mNoTrace* against its most popular competitors. Results of this study could spur some changes and improvements in the ecosystem of user-oriented privacy protection software. To the best of our knowledge, this is the first study that compares the performance of current Web privacy preserving tools in terms of performance, effectiveness, and energy consumption.

Literature in this field has studied the problem with two different experimental strategies, i.e., using hardware-based instrumentation in a controlled environment or using energy profiling software. We apply a methodology that uses hardware instrumentation to measure energy consumption while the navigation is performed on the Internet, without excluding events extraneous to the behavior under analysis, in order to provide, as much as possible, realistic results. We provide a detailed description of these approaches with an analysis of advantages and drawbacks in Section 2.

The rest of the paper is organized as follows. In Section 2 we describe the experimental strategies commonly used to perform experiments on energy consumption, highlighting the main differences with our approach. In Section 3 we describe some interesting related works. In Section 4, we discuss our methodology, while in Section 5 we show the results of the various experiments we conducted. In Section 6 we compare *mNoTrace* with the most popular tools in the same field. Finally, in Section 7 we conclude with a look at ongoing and future works.

2. Measurement approaches

Literature in this field has studied the problem with two different experimental strategies. The first approach, that we will call "In silico", is shown in Figs. 1 and 2(a)). In Biology the term "In silico" is used to mean "performed on computer or via computer simulation". We used this term to indicate experiments carried out via specialized software, internal or external, for the analysis of the energy consumption [7,22]. When using this type of measurement approach, no hardware equipment is required, resulting in a simpler and cheaper measurement setting. However, the main drawback is that energy software may be available only for certain mobile devices or Operating Systems [6,23]. Moreover, we have to emphasize that internal energy software causes an energy overhead, thus biasing the measurement results [24], while the accuracy of the results strictly depends on the supported power models and on the implemented APIs.

The second approach, that we name "In vitro", is shown in Figs. 1 and 2(b)). In Biology the term "In vitro" is used to mean experiments carried out on components of an organism that have been isolated from their usual biological surroundings to permit a more detailed or more convenient analysis. We used this term to indicate experiments carried out with software or hardware instrumentation, by analyzing the energy consumption in a controlled environment (i.e., local connections with access to Web pages saved in a dedicated Web server, access to Websites without following internal links and so on) [25,26]. The objective is to study a single phenomenon, without background noise that makes it harder to distinguish the behavior under examination. The main advantage lies in the easiness of the experimental setting, since measurements could be performed avoiding any noise due to the nature of the experiment itself (as an example, intermittent network connections that could involve tests to fail). Similar to the previous approach, an important drawback is the lack of accuracy of the experimental results. Moreover, this experimental setting prevents to analyze realistic conditions, such as human actions during browsing on the Internet (login into an account, follow a link, "like" a content, and so on).

Our methodology falls into a third category, that we call "In vivo" experiments shown in Figs. 1 and 2(c)). In Biology "In vivo" (Latin for "*within the living*") refers to experimentation using a whole, living organism as opposed to a partial or dead organism