

The Computer for the 21st Century: Security & Privacy Challenges After 25 Years

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Abstract—Decades went by since Mark Weiser published his influential work on how a computer of the 21st century would look like. Over the years, some of the UbiComp features presented in that paper have been gradually adopted by industry players in the technology market. While this technological evolution resulted in many benefits to our society, it has also posed, along the way, countless challenges that we have yet to surpass. In this paper, we address major challenges from two areas that most afflict the UbiComp revolution: security and privacy. We examine open problems on software protection, long-term security, cryptography engineering, and privacy implications. We also point out promising directions towards the solutions of those problems. We claim that if we get all this right, we will turn the science fiction of UbiComp into science fact.

I. INTRODUCTION

In 1991, Mark Weiser described a vision of the *Computer for the 21st Century* [1]. Weiser, in his prophetic paper, argued the most far-reaching technologies are those that allow themselves to disappear, vanish into thin air. According to Weiser, this oblivion is a human-not a technological-phenomenon: “Whenever people learn something sufficiently well, they cease to be aware of it,” he claimed. This event is called “tacit dimension” or “compiling” and can be witnessed, for instance, when drivers react to street signs without consciously having to process the letters S-T-O-P [1].

A quarter of a century later, however, Weiser’s dream is far from becoming true. Over the years, many of his concepts regarding Ubiquitous Computing (UbiComp) [2], [3] have been materialized into what today we call Wireless Sensor Networks [4], [5], Internet of Things [6], [7], Wearables [8], [9], and Cyber-Physical Systems [10], [11]. The applications of these systems range from traffic accident and CO₂ emission monitoring to autonomous automobile and patient in-home care. Nevertheless, besides all their benefits, the advent of those systems per se have also brought about some drawbacks. And, unless we address them appropriately, the continuity of Weiser’s prophecy will be at stake.

UbiComp poses new drawbacks because, vis-à-vis traditional computing, it exhibits an entirely different outlook [12]. Computer systems in UbiComp, for instance, feature sensors, CPU, and actuators. Respectively, this means they can hear (or spy on) you, process your data (and,

possibly, find out something confidential about you), and respond to your actions (or, ultimately, expose you by revealing some secret). Those capabilities, in turn, make proposals for conventional computers ill-suited in the UbiComp setting and present new challenges.

In the above scenarios, some of the most critical challenges lie in the areas of Security and Privacy [13]. This is so because the market and users often pursue a system full of features at the expense of proper operation and protection; although, conversely, as computing elements pervade our daily lives, the demand for stronger security schemes becomes greater than ever. Notably, there is a dire need for a secure mechanism able to encompass all aspects and manifestations of UbiComp, across time as well as space, and in a seamless and efficient manner.

In this paper, we discuss contemporary security and privacy issues in the context of UbiComp. We examine multiple research problems still open and point to promising approaches towards their solutions. More precisely, we investigate the following challenges and their ramifications.

- 1) Software protection in Section II: we study the impact of the adoption of weakly typed languages by resource-constrained devices, and discuss mechanisms to mitigate this impact. We go over techniques to validate polyglot software (i.e., software based on multiple programming languages), and revisit promising methods to analyze networked embedded systems.
- 2) Long-term security in Section III: we examine the security of today’s widely used cryptosystems (e.g. RSA/ECC-based), present some of the latest threats (e.g. the advances in cryptanalysis and quantum attacks), and explore new directions and challenges to guarantee long-term security in the UbiComp setting.
- 3) Cryptography engineering in Section IV: we restate the essential role of cryptography in safeguarding computers, discuss the status quo of lightweight cryptosystems and their secure implementation, and highlight challenges in key management protocols.
- 4) Privacy implications in Section V: we explain why security is necessary but not sufficient to ensure privacy, go over important privacy-related issues (e.g. sensitivity data identification and regulation), and discuss some tools of the trade to fix those (e.g. privacy-preserving protocols based on homomorphic encryption).

We claim that only if we get the challenges right, we can turn the science fiction of UbiComp into science fact.

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