

Empowering Users' Privacy Rights in the Internet of Things

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Abstract—Internet of things (IoT) devices are everywhere, since the birth of ubiquitous computing that human every day life is envisioned containing millions of devices that control every aspect of our lives. Today we have smart cars, smart houses, smart cities, wearables among other things that use various types of devices and various types of networks to communicate. These devices create new ways of collecting and process personal data from users and non-users. Most end users are not even aware or have little control over the information that is being collected by these systems. This work takes an holistic approach to this problem by first doing a literature review, then by doing a survey to gather information about the general knowledge of Portugal's population in this very topic and then, based on the information gathered, it is proposed a system that gives users information about the devices that are nearby and how to protect the data that they do not want to share with these devices, this system is capable of detecting what type of devices are nearby, what kind of data is collected by these devices, show privacy choices to the user when it is possible to do so and what can be done to protect unwanted data from being collected.

Index Terms—privacy, Internet of Things, ubiquitous computing, privacy assistant

I. INTRODUCTION

Privacy as we know it is a somewhat recent concept [1], [2], before the digital age there was barely any notion of privacy for most people. For many centuries most people used to reside in small communities where they were continuously involved in one another's lives. Even more recent is the idea that privacy is a crucial component of personal security, in contrast to the undeniable necessity of public security, including the requirement for guarded walls and closed doors. Long seen as a luxury, privacy is still usually regarded as a good to have rather than an essential requirement, even though it is acknowledged as a human right, as present in article 12 of the Universal Declaration of Human Rights [3]: "No one shall be subjected to arbitrary interference with his privacy, family, home or correspondence, nor to attacks upon his honour and reputation. Everyone has the right to the protection of the law against such interference or attacks". Privacy can be defined [4], [5] as the right to govern how personal information and data is collected, stored, and used, it frequently involves handling sensitive information with care, and as such, organizations must be open and honest about the kind of data they plan to gather, why they need it, and where

and with whom they plan to share it. Users should have the right to control their shared information.

This definition can cause some confusion with the idea of security [6] and although privacy and security are interconnected, security involves measures taken to safeguard data from risk, threat or danger, it frequently alludes to safety. It is the practice of keeping users' personal information and data safe and preventing unauthorized access to it. The primary contrast between privacy and security is that the former deals with information personal to individuals and how they want their data used and maintained, whilst the latter deals with its protection from possible threats. Security can exist without privacy, but the opposite is not true. For managing sensitive and personal data, privacy and computer security are equally crucial.

Concerns about digital privacy have been growing [7]–[9] in the last few years, especially after the Anonymous decentralized hacker group cyber attacks, WikiLeaks and Snowden's leaked top secret documents from United State's National Security Agency. These concerns can be noted with the increase of written literature on the subject, when searching for terms like "privacy", "online privacy", "digital privacy" in Google Scholar, ACM Digital Library or Science Direct it can be seen that, in the last 5 years, it returns about 5000000, 650000 and 80000 documents respectively, including articles, books, conference papers etc.

Most research has been done with focus on the web, while privacy in IoT systems has not been explored as much, although IoT systems have been growing each year, this creates new ways to interact, collect and analyze data. Because it already exists a healthy amount of research out there focusing on privacy on the web and not on IoT privacy, it is a much more fertile ground to explore the theme of privacy in the context of Internet of Things.

IoT is a term that began being used in the 90's, a connection can be drawn with Mark Weiser's article on ubiquitous computing [10] and the rise of devices of various sizes that communicate with each other to do various (small) tasks, that make Weiser's idea a reality. These devices are used in various applications, beginning at home [11] with thermostats, fridges, microwaves, etc, in smart cars [12], in the education system [13], in our clothes and our watches [14] and even into outer space [15]. IoT resources may include IoT equipment (like

smart home assistants and autonomous vehicles), IoT services (like video analytics services linked to smart cameras and indoor position tracking systems), or IoT apps (like smart TV remote apps) that track and use information about us. The first use of the term *Internet of Things* was in 1999 by Kevin Ashton [16], executive director of the Auto-ID Center of MIT, during a presentation for Procter & Gamble.

The Internet of Things can be defined as: “An open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment” [17].

IoT is one of the fastest growing technologies [18], it is predicted that it will grow into the trillions of devices by 2030 [19], and with this expansion new security vulnerabilities and data gathering dangers appear, the lack of security in these devices makes them ideal targets for privacy violations and inadequate customer disclosure of device capabilities and data practices aggravates privacy and security issues.

Privacy in IoT systems is not seen as a crucial factor in development [20]. Specific standards for privacy options have been imposed by data privacy regulations including the General Data Protection Regulation (GDPR) and California Consumer Privacy Act (CCPA), but even these regulations have been criticized [21]–[25].

II. LITERATURE REVIEW

In this section the existing literature is discussed, the chosen literature is based on the following research questions:

Q1: What are the tools available related to IoT that empower users to protect their privacy rights?

Q2: What issues are prevalent in IoT that make it difficult to address privacy and security problems.

Some relevant topics are discussed before analyzing the proposals that the literature regards as solutions to resolve privacy issues in IoT.

A. Privacy Paradox

The use of a variety of digital devices have numerous advantages, but they also bring with them the ubiquity of data capturing equipment, therefore, it is understandable why the majority of online users have serious concerns about the privacy of their personal data. However, the opinions expressed are starkly at odds with the reality, according to Thomson et al. [26] report on the state of privacy, that just one in four European users read the terms and conditions in their entirety prior to making an online purchase or subscribing to a service, 59% admitted to only quickly scanning the terms and conditions before completing a purchase, while 14% admitted to never reading them at all, 30% of the respondents would even swap their email address to win a reward, or entry into a raffle, while 17% would do so to get an app and 30% would do it for money.

This is what is called a privacy paradox, there have been multiple papers written on this subject [27]–[31], some papers attempt a theoretical explanation while others attempt an

empirical one. There has been very different interpretations or explanations of this paradox, a few papers [32]–[34] apply the theoretical concept of the *homo economicus* [35], which is the representation of people as beings who constantly act in a way that is logical and self-interested, not worrying about morality or ethics, and who do so to the best of their ability, to the context of privacy. Different cognitive biases and heuristics can influence how consumers make decisions, according to several studies on consumer choice behavior [36]–[39]. According to several articles [40], [41], this paradox might be explained by the fact that some people have genuinely experienced online privacy assaults and that most privacy views are therefore based on heuristics or secondhand accounts. Taddicken’s study [42] argues that peer pressure is the reason people have this contradictory behavior, Norberg et al. [43] explains this paradox by suggesting that while perceived risk affects reported attitudes and behavioral intentions, trust has a direct impact on privacy behavior, while others [39], [44] rely on quantum theory. Brandimarte et al. [45] have explored the idea that when it comes to their data privacy, users have an *illusion of control*.

This paradox has been proven to be vitiated by a number of empirical studies [40], [46]–[48], online privacy practices are founded on separate privacy mindsets and so they are not inherently paradoxical.

B. Literature overview

There have been a number of systematic literature reviews (SLR) [49]–[52] and systematic mapping reviews [53], [54] done to study privacy and security issues in IoT.

In Gupta and Ghanavati’s [49] SLR, the authors review papers with methodologies and techniques that identify privacy risks or notify users about these risks. They divide the literature into the following categories: ‘Ontological Modeling and Semantic-based Approaches’, ‘Data-Driven Approaches’, ‘Source Code Analysis-based Approaches’, ‘User Studies and Survey-based Approaches’, ‘Blockchain-based Approaches’ and ‘Architectural and Framework-based Approaches’. They then examine current literature on these three prerequisites. The findings show that: most works concentrate on single IoT devices when addressing privacy threats; When analyzing privacy issues, key privacy factors such as data reduction and data aggregation are overlooked; existing studies ignored the sensitivity of the obtained information; most useful studies did not include a diverse range of users when assessing privacy problems; no work has been done to discover compliance difficulties between an IoT application and different privacy rules; and current research does not place a premium on providing consumers with real-time privacy notices. However, this SLR has the following limitations: the authors only chose articles and not thesis or books and from the selected papers, only the ones written in english were considered.

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Kühtreiber et al. [50] conduct a survey of the frameworks and tools created for developers, particularly in the case of IoT, and they conclude that present solutions are difficult to

use, only effective in specific circumstances, and insufficient to address the privacy problems inherent in IoT development. This study lacks a comprehensive gap analysis of the chosen literature and it does not specify the research questions that define the relevancy of the selected papers.

Sicari et al. [51] conduct an analysis of recent studies and active initiatives that emphasize IoT privacy and security solutions. They begin by outlining the needs for IoT privacy and security, including access control, confidentiality, and authentication. They then review the literature that already exists in relation to these three needs. They concluded that IoT privacy concerns are only partially investigated and need further attention. The study, however, has its shortcomings, the analysis of prior research focuses primarily on security needs and leaves out privacy considerations, they don't perform a thorough gap analysis on the publications that were examined, and they don't provide a thorough summary of the future research topics in the field of IoT privacy that need more attention.

Lin et al. [52] undertake a literature review to find security and privacy concerns in the network layer, perception layer, and application layer, the three IoT architectural layers. Confidentiality, integrity, availability, identity and authentication, privacy, and trust are the first six essential security properties that the authors list for these levels. Then, for each of the three tiers, they examine a number of security attacks. They conclude by providing a brief overview of a number of privacy-preserving data procedures, including data gathering, data aggregations, and data analysis stages. They do, however, primarily focus on the security elements of the IoT and see privacy as one of the most important security characteristics, as was already established. Additionally, a thorough gap analysis to determine the shortcomings of the previous works is not done in the research.

C. Differential Privacy

The notion of differential privacy, according to Michael Kearns [55], is based on three important principles. The first being that "differential privacy requires that adding or removing the data record of a single individual not change the probability of any outcome by much". The second principle being that "no outside observer can learn very much about any individual because of that person's specific data". The third important principle being that "for every individual in the dataset, and for any observer no matter what their initial beliefs about the world were, after observing the output of a differentially private computation, their posterior belief about anything is close to what it would have been had they observed the output of the same computation run without the individual's data".

Differential privacy has the potential to significantly increase individual privacy protection, by purposefully adding noise into a dataset, it gives plausible deniability to any individual who may have had their data exploited while still being able to calculate statistics with relatively high precision. Although algorithms that deal with notions of fairness, ethics,

and privacy are hard to implement because of the subjectivity of these concepts, and differential privacy algorithms are no different, they can still help in regards to addressing technology's inherent moral quandaries.

There exist other algorithms that aim to preserve privacy in the same way as differential privacy such as Google's box blurring algorithm [] that is used in the map's street view, Microsoft's Visor [] which is a video-analytics-as-a-service tool, Shokri and Shmatikov's [] system for collaborative deep learning, but these algorithms suffer from heavy computational overhead, inner attacks, or nonprovable privacy.

add more articles/content on this subsection

Zhao et al. [56] conduct a SLR on differential privacy for Unstructured Data Content.

This article has presented differential privacy methods for sensitive content in these unstructured data. We have identified that unstructured data are obfuscated based on appropriate vector representations, specific privacy models, and vector reconstructions. We have discussed possible challenges faced with these privacy methods. We have provided an overview of privacy guarantees and utility losses in these methods and possible approaches to improve data utility.

D. Proposed solutions

1) *Creating new ways for user awareness:* There has been some work done to determine the users awareness of their actions online regarding their privacy. Skirpan et al. [57] built an interactive theatre experience, this was created to try to prove that a simulated experience with a credible privacy problem may encourage people to take action before actually encountering a catastrophe. The plot of the play consist in a fledgling tech company that unveiled its revolutionary AI technology while dealing with a company whistleblower and an untimely zero-day hack on their system. The public is able to interact with the actors and influence how the story plays out. Audiences and actors were given the chance to try on roles, behaviors, and opinions that they would not normally have access to in ordinary life. The authors had interviews and surveys done after the plays with audience members however they only did interviews halfway through production and only a small fraction of the audience actually participated in this data collection, they also noted that after contacting people months after the interviews that they did not really changed their behaviour regarding their privacy rights.

2) *Legislation:* Some papers seek to improve legislation [58], [59] because otherwise, in their view, privacy rights won't be respected if they are not enforceable legally, they defend that without the express agreement of the individual concerned, private information obtained by IoT devices must not be retained or processed in any form, and necessary procedures must be taken to guarantee that the data collected is not that of an unrelated individual. But better protection laws for the user would also create opposition from most companies that want to extract as much private data from their users without (m)any restrictions in order to increase their profit margins.

3) *Privacy through security*: Sun et al. [60] design a lightweight communication strategy for a remote-control system, employing two types of Virtual-Spaces to achieve the aim of identity announcement and data exchange. They constructed a prototype system of the scheme and tested it on the Freenet, demonstrating that the method can effectively resist the influence of flow analysis on communication anonymity while preserving communication data security.

4) *Architecture / Framework Proposals*: Antunes et al. [61] do a SLR on federated learning in the area of healthcare and make an architecture proposal. The technique known as federated learning allows for the distributed training of machine learning models using remotely hosted datasets without the requirement for data amplification. The fundamental goal of the proposed architecture is to allow healthcare institutions that have access to sensitive medical information to use it in distributed data analysis and machine learning research while ensuring patient confidentiality. Because information transmitted among institutions need confidentiality guarantees for learning model parameters and analysis results, the architecture can adopt a number of ways based on a zero-trust security paradigm [62]. Furthermore, the institutions develop a learning algorithm verification system that can store and disseminate manifestos, as well as engage in distributed analytic procedures that need unanimous agreement from all participants. This study also demonstrates that previous literature implies that homomorphic encryption and differential privacy are effective approaches for preventing data breaches without incurring prohibitively high computing costs.

Opara et al. [63] present a system for spotting possible problems with privacy or security regulations in the early stages of development, this approach is intended at developers. The paper proposes a domain-specific ontology for modeling IoT security and privacy policies, a notation for representing and validating IoT security and privacy policies, a set of guidelines and rules for detecting IoT policy errors, and a tool for visually modeling and capturing IoT security policies and discovering policy problems. Although the framework that is presented is theoretically promising it has not been tested in a real environment so the effectiveness can't yet be measured. The authors also don't compare their proposal with others already available.

5) *Blockchain*: Blockchain proposals that try to resolve privacy issues in IoT.

6) *Other?*: Zhu et al. [64] present a hybrid sensor system that safeguards privacy while also monitoring parking availability. The researchers merged IoT sensing with crowdsensing and enhanced it with privacy-preserving methods. The authors employed physical hazy filters to mask IoT sensors in IoT sensing, and a cryptographic technique based on cryptographic commitments, zero-knowledge proofs, and anonymous credentials in crowdsensing. In addition, crowdsourcing was used to create a machine learning model for parking recognition in the presence of foggy filters. The report included proof-of-concept prototypes such as a Raspberry Pi system and a mobile app, as well as an evaluation study of the machine learning model

and the effects of crowdsourcing.

7) *Privacy Assistants*: There exists a number of privacy assistants in the market. Privacy assistants have the objective of giving the user flexibility in choosing the preferred privacy options in available applications, most are used in smartphones, very few are made for devices in the internet of things.

The Carnegie Mellon University CyLab, which is the university's security and privacy research institute, started developing in 2019 an IoT Infrastructure that intended to be free of privacy leaks and software covered by their Secure and Private IoT Initiative 2019, this project would fall under their main research theme of Trust. In this project they started the design of a Personalized Privacy Assistant (PPA) [65], this would involve the use of semi-structured interviews with 17 participants to examine user perceptions of three hypothetical PPA implementations, each of which is potentially more autonomous, while outlining the advantages and disadvantages of each implementation. The interviews were divided into three sections: exploratory, anchoring and the PPA; While the exploratory phase's purpose was to learn about participants' attitudes and understanding of IoT, the anchoring phase aimed to normalize participants' basic understanding of how IoT functions. In order to get people to think about potential privacy concerns towards the end of the anchoring section, the authors asked participants about their opinions on data privacy. In the PPA section, it was proposed the idea of a PPA for IoT as a potential future project. The authors clarified that the PPA could distinguish between active data requests such as a gadget asking biometric information from the user's health tracker and passive data collection such as a smart device with a microphone that could record people's utterances while they were nearby. The Notification, Recommendation, and Auto implementations of an IoT PPA were the three that the authors and attendees discussed. Notification PPAs can determine which adjacent devices are requesting data and alert users to those devices' presence and requests so that users can approve or reject each request. Building on notification PPAs, recommendation PPAs offer consumers advice on how to share their data based on their preferences. The user's data sharing decisions would be made by auto PPAs. This would lessen the cognitive load on consumers but also take away their ability to influence the process. They found that The participants' attitudes regarding the various implementations were generally favorable, although they also voiced worries, which varied depending on the degree of automation. Given the divergent motivations of participants some desired increased control, while others wished to avoid being overtaken by notifications and the lack of agreement regarding the optimal PPA implementation.

After the design phase, the institute implemented a privacy assistant (PA) [66], the authors called it IoT Assistant, because the predominant approach of "Notice and choice" for data privacy protection, they decided the PA would also fall into this approach, but because many systems implement notice as a form of consent, without sometimes offering choices to the end user, they also wanted this work to provide a conceptual

framework that views user-centered privacy choice as well as a taxonomy for practitioners to use when designing meaningful privacy choices for their systems. The authors define meaningful privacy choices as "the capabilities provided by digital systems for users to control different data practices over their personal data". They extend the notion of privacy choices with five facets: effectiveness (the opportunity to establish privacy preferences that precisely and completely match the data collection and use methods that a user is okay with), efficiency (the capacity to specify these options with the least amount of effort and time), user awareness (where significant privacy options should be prominently and clearly communicated to users), comprehensiveness (users should understand their options, how they affect the gathering and potential use of their data, as well as what conclusions might be drawn from this data and the potential repercussions of these conclusions) and neutrality (meaningful privacy decisions should not be subject to manipulation or bias). The IoT Assistant offers four privacy settings, giving end users a variety of alternatives to better suit their varied privacy preferences and as a result, privacy options are more effective in the IoT environment. The IoT Assistant acts as a centralized privacy choice platform by implementing various privacy options, allowing consumers to more effectively govern their data privacy in IoT. The three IoT system discovery modes that the IoT Assistant supports are QR codes, push notifications, and location-based map interfaces. These discovery tools are probably going to make users more aware of the installed IoT devices and the privacy options they have. Additionally, the united viewpoint of the integrated notification and option in the IoT Assistant gives succinct yet thorough information regarding IoT data practices to help users better understand the implications of their privacy choices. Additionally, the authors work to implement the integrated notice and option in the IoT Assistant without bias or framing, attempting to offer consumers a neutral space to execute their privacy choices. Although the authors consider the IoT Assistant to be a significant step towards "meaningful privacy options" in IoT, this assistant still has many issues such as this application is still in the early stages of its existence, and because this was created in 2020 and we are in 2022 there was not much growth. Maybe the main reason this application was not able to be developed further is that the application itself serves to show the user the data that is already in the IoT infrastructure that was created before, and as such it is not capable of identifying new IoT devices without the end users themselves create on the infrastructure's main webpage [67] a new entry for the device in question that the user wants to interact with. Another reason that cripples this application and many like it that want to provide better privacy in IoT systems is that many systems don't offer any type of privacy choices to the end user or to other users that are not the intended end users but the devices are still collecting data about.

The IoT infrastructure that was developed [67] is built on an open, distributed design that allows for the deployment and management of IoT resources to be carried out by any number of actors. Part of this infrastructure is the Internet

of Things Resource Registry, it is a web platform that enables resource owners to declare not only the place where a resource is deployed but also data practices like the reason(s) for a particular data collecting process, the level of detail in the data being gathered, retention, the recipients of the data, and more. Additionally, it discloses any user-configurable privacy settings that might be connected to a particular resource.

A similar project is LTEye [68] that is an open platform that provides granular temporal and spatial analytics on the performance of LTE radios without access to private user data or provider assistance. Despite the presence of multipath, LTEye uses a revolutionary extension of synthetic aperture radar to communication signals in order to precisely pinpoint mobile users.

TODO: from here forward

III. CHALLENGES

IoT is composed of a complex web of architectures, applications and technologies. In terms of architectures, it can be decomposed in three layers: the perception layer, the network layer and the application or business layer.

IV. METHODOLOGY

It is conducted a systematic literature review of the most relevant papers discussing methodologies and techniques for the protection of users' privacy data with special focus on IoT systems. For this SLR I considered focusing only on papers from the last 12 years, from 2010 until 2022, since papers before then become out of date with the evolution of technology. I reviewed 100 (***number to be adjusted**) papers published in top computer science, security, privacy and software engineering outlets.

I followed Keshav's three-pass approach [69] when choosing which papers to read fully and which ones to ignore, first I would read the title, abstract, introduction and conclusion and briefly skim the rest of the paper and then decide if it was worth reading any further, the focal point in this phase was answering the following question: does the paper present a new methodology or interesting angle to tackle users' privacy concerns? Only then the document would be read in its entirety while ignoring any tables, figures, images or graphs. If the paper failed to present any interesting idea, approach, or technique it would be discarded, but if not, it would be read carefully from the beginning again in order to fully understand what it presents.

The proposed methodology is composed of two phases, the first phase consists of making a study on the region's general concern with their privacy when using and interacting with IoT devices, their knowledge of privacy rights, what they do to protect their privacy rights. On one side the objective of this study consist in demystifying the privacy paradox in the region and gather information about their idea to solve this problem with respect to IoT devices. The second phase consists in doing an application that can detect IoT devices nearby the user with at least a 10 meters radius. The

application should do the following when detecting a device: 1. it should show some information about the device; 2. it should categorize the device; 3. it should provide the user with privacy options, if the device allows the user to decline data harvesting. This application at first sight might appear to be a mere privacy assistant but it's not, because IoT assistants merely choose what privacy options the user first sets and maintains it for every other application that the user might use. The proposed app doesn't have the objective to conform to the user's preferred privacy choices, it merely informs the user about nearby IoT devices and can provide the user with privacy options. But the main objective is creating awareness in individuals about the various devices that are around and make the user questions their choices.

V. STUDY

This study was done to try to understand people's perception of IoT and their privacy practices online. It was partially based in a study done in the Philippines by the government in the context of their privacy act of 2012, this was the second survey done on the population. This survey was done through the internet, it was created in google forms, this way it is guaranteed to reach most people in the country.

VI. APPLICATION

I created something and...

VII. DISCUSSION

The study found the following... The app...

VIII. FUTURE WORK

Although there exist some hardware devices that can detect some devices on some networks, like ZigBee or Bluetooth LE, namely IoT sniffers and there exist some georeferencing applications that try to pinpoint certain IoT devices, there is still a need for some kind of device or framework that is network agnostic and can detect where the devices are located and what kind of data the IoT devices that are around it are collecting. This gadget should also be capable of informing the users about the privacy notices of the devices and what can the users do to safeguard their data. The IoT sniffers that are available are primarily used in the detection of problems in the communication of devices in the network or to solve problems of interoperability between different IoT networks. There are many obstacles that impede the creation of such a gadget and the fact that it still doesn't exist anything like it shows that maybe there is not enough interest from users or researchers to focus on such an endeavour or the complexity of such a task is greater than the rewards.

IX. CONCLUSION

In this thesis I explored people's perception of privacy of IoT systems and made an application that aims to create more awareness in users about their environment and the IoT devices that inhabit it.

ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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