A Survey of User Perspectives on Security and Privacy in a Home Networking Environment

NANDITA PATTNAIK, SHUJUN LI, and JASON R. C. NURSE, University of Kent, UK

The security and privacy of smart home systems, particularly from a home user’s perspective, have been a very active research area in recent years. However, via a meta-review of 52 review papers covering related topics (published between 2000 and 2021), this article shows a lack of a more recent literature review on user perspectives of smart home security and privacy since the 2010s. This identified gap motivated us to conduct a systematic literature review (SLR) covering 126 relevant research papers published from 2010 to 2021. Our SLR led to the discovery of a number of important areas where further research is needed; these include holistic methods that consider a more diverse and heterogeneous range of home devices, interactions between multiple home users, complicated data flow between multiple home devices and home users, some less studied demographic factors, and advanced conceptual frameworks. Based on these findings, we recommended key future research directions, e.g., research for a better understanding of security and privacy aspects in different multi-device and multi-user contexts, and a more comprehensive ontology on the security and privacy of the smart home covering varying types of home devices and behaviors of different types of home users.

CCS Concepts: • Security and privacy → Human and societal aspects of security and privacy;

Additional Key Words and Phrases: Security, privacy, systematic literature review, user perspectives, home, networking, IoT, smart devices

ACM Reference format:
Nandita Pattnaik, Shujun Li, and Jason R. C. Nurse. 2023. A Survey of User Perspectives on Security and Privacy in a Home Networking Environment. ACM Comput. Surv. 55, 9, Article 180 (January 2023), 38 pages. https://doi.org/10.1145/3558095

1 INTRODUCTION

Modern information and telecommunication technologies (ICTs) have made today’s homes more connected and digitized. With the rapid advancement of artificial intelligence (AI) technologies and their use in modern homes, the more traditional term “home network” is increasingly replaced by the more recent one “smart home,” which often covers the use of Internet of Things (IoT) home devices with “smart” functionalities and relying on data exchanges with the Internet. Today’s smart homes are equipped with many computing/networking and smart devices, sensors, systems, and software applications. According to a 2020 report [101], the average number of connected devices in a household in most Western countries is over seven. All home devices communicate with each other and the network/Internet following a range of different protocols, while
interacting with internal and external entities including home users and other individuals [19]. This continuously evolving home networking environment offers a multitude of benefits and opportunities to home users but also simultaneously presents many challenges, including varied security threats and privacy issues.

Current research in this area has a significant focus on understanding the home users’ perspectives, reflecting on their awareness [58, 95, 188, 202], behavior [8, 57, 77, 106, 179], actions [18, 31, 53, 138], and concerns [13, 104, 203]. In order to understand the scope and nature of these studies and ascertain the direction of future research, it is important to collate, review, and analyze the relevant research in this field. Past reviews on related topics are more focused on product-centric analyses [79, 160, 161, 188], are technical and security related [17, 78, 151], consider the smart home in general [54, 184, 194], or are purely privacy oriented [96]. Reviews that covered related user perspective studies are either too dated [80, 191] or have a narrower scope, e.g., privacy only [96], or are focused on a particular segment of home users (older users’ privacy attitude) [142, 180].

Hence, our goal in this article is to review the current research in this field and determine the areas where further research is necessary. With this in view, we need to explain two important terms, which are used throughout this article. First, we consider the term “home” as a relatively broader concept, covering traditional family residences, shared student accommodations, shared flats/houses, residential care homes, and nursing homes. We use the term “home network” to signify a network of all computing and connected devices in a home that may or may not be considered smart devices. When we use the term “smart home” or “smart home network,” we refer to a slightly narrower concept, i.e., a home network that includes at least one or more smart devices, which can be controlled from a smart device or a personal computer.¹ Note that smart mobile devices and wearables may not be considered as smart devices by some home users and vendors, so the term “smart device” and “smart home” can have different meanings for different people. Second, “user perspectives” in our article will incorporate a broad range of topics including mainly the following:

UP1: home users’ behaviors, awareness, perceptions, attitudes, practices, and concerns relating to security and privacy of the home network;
UP2: the relevant contexts in which UP1 occur or change;
UP3: effects of different demographic factors such as age and gender on UP1; and
UP4: theoretical frameworks that can help explain UP1.

According to the systematic meta-review we conducted as part of the research reported in this article, covering 52 literature reviews published between 2000 and 2021 (Table 2), only 10 papers cover some (mostly an incomplete set of) topics related to “user perspectives” and only one paper [80] published in 2012 covers a more complete discussion of related topics. The results of our meta-review indicate a gap of more recent literature review on security and privacy of smart home systems from a home user’s perspective.

Our work was conducted in a two-staged approach. In the first stage, we conducted the above-mentioned systematic meta-review, to have a better understanding of related literature review papers. The results of the meta-review helped shape the methodology of a subsequent systematic literature review (SLR) in the second stage.

Key contributions of our work and noteworthy findings from our SLR are summarized below.

1 Methodologically, we used a meta-review to systematically examine past literature reviews and to facilitate design of a follow-up SLR, which is a review method that has not been used in similar past work.

¹A similar definition can be found at https://www.lexico.com/definition/smart_home.
Compared with past literature review papers, our SLR has the most comprehensive coverage of different user perspectives related to security and privacy of smart home systems and covers more recent research papers from 2010 until 2021.

A number of key findings and recommendations for future research directions are obtained from our SLR, many of which have not been discussed in previous review papers. We list these below.

- The hybrid nature of a modern home with multiple (inter-)connected devices, including different types of traditional and “smarter” devices, is still under-studied.
- The existence of multiple and different types of home users has not been sufficiently considered.
- Study of home network and related security and privacy issues in different contexts and various cross-contextual effects are still under-researched areas.
- More research is needed to better understand data flows across multiple devices and users and in different contexts.
- Some demographic factors such as location and income of home users are less studied than others.
- Research on home users’ perspectives in relation to the security and privacy of the home network is predominately focused on a small number of smart devices, e.g., smart speakers and smart cameras.
- More advanced theoretical and conceptual frameworks, such as smart home security ontologies, need to be developed to support a more holistic view of security and privacy aspects of a home network environment.

The rest of this article is structured as follows. Section 2 discusses the general methodology followed to conduct both studies. Sections 3 and 4 explain the methodology and results of the two stages (the meta-review and the SLR), respectively. Note that our meta-review plays the role of the related work section of a more traditional literature review paper. Section 5 summarizes our main findings and recommendations for future research, while the later section concludes the article.

## 2 GENERAL METHODOLOGY

As mentioned in the previous section, the methodology we followed is two-staged: (1) a meta-review to gather the related reviews in this field more systematically and to help formulate research questions for the SLR and (2) an SLR to collate and analyze the original research in this field. For both the meta-review and the SLR, we followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method [128], a widely used procedure for conducting SLRs. The procedures followed in both stages of our study are illustrated in Figure 1.

The PRISMA procedure to identify eligible papers for the systematic review process includes four main steps: (1) identifying pertinent records, (2) screening the selected records based on the exclusion and inclusion criteria, (3) assessing the eligible records, and (4) selecting eligible items for the final study. Since the results of the meta-review were produced systematically and contributed to the selection of our research questions for the SLR, we decided to present both the above scientific processes in one flow diagram presented in Figure 1. For ease of understanding, both these processes are color coded (blue for the SLR and green for the meta-review) to represent two different processes.

For both stages, a selection of three major scientific databases, Scopus, ACM Digital Library, and IEEE Xplore, were considered. We decided to include Scopus as it is regarded as a very comprehensive and interdisciplinary database [21]. Note that Scopus is a product of the largest scientific publisher Elsevier, so research papers published by Elsevier are well covered by Scopus. In addition, we observed that research papers published by other mainstream publishers such as Springer and
Fig. 1. The PRISMA procedures used for the meta-review and the SLR.

John Wiley & Sons, Inc. are substantially indexed by Scopus. We decided to include ACM Digital Library and IEEE Xplore as additional databases because ACM and IEEE are the two most important subject-specific publishers for cyber security and smart home research. Although the same query was used for all the databases, each database offered different searching tools; i.e., Scopus supported searching directly into paper title, abstract, and keywords (called "metadata"), but ACM Digital Library and IEEE Xplore did not offer such a direct search option, so we decided to search into the abstract only. The results were filtered to include only “Journal articles,” “Conference proceedings,” “Conference reviews,” “Reviews,” and “Articles in press,” published in the English language. Specific keywords used, the inclusion and exclusion criteria for each of the reviews and the period of search, have been included in the respective methodology sections.

To store, categorize, and analyze our data in both stages, we used a widely used research software system called MAXQDA (http://www.MAXQDA.com/). MAXQDA has several useful tools to support different qualitative and quantitative analysis tasks such as “Smart coding tool,” “Document variable analysis,” “Visual tools,” “Memos,” and “MaxDictio,” which were very helpful in our analysis.

3 META-REVIEW

The meta-review aims to identify, collect, analyze, and synthesize the review papers on the subject of security and privacy at home, and helps to formulate the research questions for the main SLR. The meta-review concept is similar to scope review [132], which can be used as a precursor to an SLR to help guide the design of the SLR.

3.1 Methodology

Following our research aim, the meta-review focused on the research question: How have existing review papers in the area of security and privacy of home networking covered research on user perspectives?
3.1.1 Search Keywords. Table 1 shows the keywords we used to conduct our search queries. The search strategy includes three main components: the first subset of keywords captures the home networking and smart home context, the second limits our searches to security and privacy-related papers, and the last one covers several typical keywords indicating the nature of the paper as a review or systematization of knowledge (SoK) paper.

To follow the screening and eligibility checking steps of the PRISMA process, a set of exclusion and inclusion criteria were established. A paper meeting any one of the exclusion (or inclusion) criteria was excluded (or included).

3.1.2 Exclusion Criteria. Papers meeting the following exclusion criteria were excluded:

- Papers published before 2001.
- Non-English papers.
- Papers that do not cover the home context (e.g., those covering industrial IoT).
- Conference reviews or book chapters.
- Papers that do not cover any security or privacy factors.
- Papers that are not review papers excepting non-review papers that report any taxonomy covering security, privacy, or user perspectives of the home network.

3.1.3 Inclusion Criteria. After excluding papers based on the exclusion criteria, those meeting at least one of the following inclusion criteria were selected:

- Papers focusing on issues and solutions in the area of security and privacy of the home network.
- Papers that systematically reviewed smart-home- and home-network-related products or applications.

The non-review papers reporting on ontology or taxonomy relevant to the subjects were considered as pseudo-reviews and were included in the study because they normally systematically conceptualize relevant topics.

In the following, we present the results of the meta-review.

3.2 Results and Discussion

Figure 1 (colored in green) shows the results from each step of the meta-review. The initial searches gave us 2,670 papers in total. After removing duplicates, we had 1,647 papers to screen. Following the exclusion criteria in Section 3.1.2, we ended up with 257 papers for further screening. After a scan of those papers’ abstract, introduction, and conclusion sections and applying our inclusion criteria presented in Section 3.1.3, 52 papers were included for final analysis. The screening and filtering steps gave us a clear indication of reviews that were conducted in the past on relevant topics, helping to inform the second stage of our work (i.e., the SLR). Table 2 presents an overall comparison of related study with the current research. Note that although all included papers are review papers, only some can be considered SLR (i.e., others were not done following a systematic approach). Table 3 depicts the thematic categorization of the 52 papers in our study based on the broad overall theme that the reviews conveyed.
### Table 2. Comparison of the Current Study with Related Work

| Year(s) | Reference(s) | Security | Privacy | Smart Home | Holistic | Multi-Device | Awareness | Concerns | Behavior | Multi-User | Demographics | Contextual | Theoretical | SLR | Meta-Review |
|---------|--------------|----------|---------|------------|----------|-------------|-----------|----------|----------|------------|--------------|-----------|-------------|-----|-------------|
| 2000–2016 | [111]       | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [35, 90]    | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [180]       | ✓         | ✓         | ✓          |          | ✓           | ✓         |          |          | ✓          |              |           |             |     |             |
|         | [80]        | ✓         | ✓         | ✓          | ✓         | ✓           | ✓         |          |          | ✓          | ✓            | ✓         |             |     |             |
|         | [191]       | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [198]       | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
| 2017    | [2, 25, 115]| ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [10, 67]    | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [14]        | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
|         | [142]       | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
|         | [24]        | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
| 2018    | [78]        | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [17, 62, 66]| ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [158, 184]  | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [96]        | ✓         | ✓         |            |          |             |           |          | ✓         | ✓          |              | ✓         |             |     |             |
| 2019    | [12, 99]    | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [16, 124]   | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [41, 74, 75, 133, 185]| ✓ | ✓ |            |          |             |           |          |          |            |              |           |             |     |             |
| 2020    | [51, 55]    | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [45, 109, 151, 159, 175]| ✓ | ✓ |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [131, 194]  | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [152]       | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [54]        | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
| 2021    | [33, 52, 69, 172]| ✓ | ✓ | ✓          |          |             |           |          |          |            |              |           |             |     |             |
|         | [43]        | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
|         | [11, 127]   | ✓         | ✓         |            |          |             |           |          |          |            |              |           |             |     |             |
|         | [147]       | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
|         | [107]       | ✓         | ✓         | ✓          |          |             | ✓         |          |          |            |              |           |             |     |             |
| 2022    | **Our work**| ✓         | ✓         | ✓          |          | ✓           | ✓         | ✓         | ✓         | ✓          | ✓            | ✓         |             |     |             |

### 3.2.1 Security and Privacy in General

Nineteen papers covered by the meta-review focus on various common issues arising from security and privacy problems in a smart home. DeFranco and Kassab’s article [52] covered the broad theme of general research avenues around smart home. While Kuyucu et al. [99] reviewed papers relating to both privacy- and security-related issues and solutions, Liao et al. [109] explored security problems, challenges, techniques used, and solutions available from a mobile computing point of view. Talal et al. [175] focused on security issues of the tele-medicine environment, exploring smart home issues and solutions in general and hardware sensors, protocols, wireless networks, and security architecture in particular. Philip et al. [147] published a similar study on home health monitoring systems. Bolton et al. [33] surveyed the security and privacy challenges of virtual assistants such as “Siri” by Apple. Barriga A. and Yoo [23] discussed existing security mechanisms and approaches in a smart home automation system, while
Table 3. Categorization of Review Papers into Different Categories (Period: 2000–2021)

| Category                      | 2000–2016 | 2017 | 2018 | 2019 | 2020 | 2021 | (#) |
|--------------------------------|-----------|------|------|------|------|------|-----|
| Security and privacy in general | [111]     | [25, 115] | [17, 23] | [12, 99, 124, 185] | [55, 109, 147, 151, 159, 175] | [33, 43, 52, 172] | 19  |
| User perspectives               | [80, 180, 191, 198] | [14, 24, 142] | [96] | [124] | – | [107] | 10  |
| Threats and attacks             | [90] | [2, 25] | [78] | [16, 74] | [45, 51, 109] | – | 9   |
| Security and privacy solutions  | – | – | [17, 62, 66, 158] | [41, 75, 99, 133] | [131, 151, 159] | [11, 127] | 13  |
| Smart devices                   | [35, 90] | [10, 67] | [184] | – | [54, 152, 194] | [69] | 9   |

Batalla et al. [25] analyzed the security requirements and countermeasures used in a general IoT architecture and suggested an extendable home area network with multi-level privacy and security to be managed by a trusted external actor to lessen the burden on home users. Other topics covered in some reviews include smart home data protection issues [43] and security issues in different layers of the smart home network [172].

Three papers chose to focus on specific areas in smart home security. These include Ambient Intelligence (AmI) applications and their privacy issues by Lopez et al. [111], major wireless protocols such as Zigbee and Z-wave by Marksteiner et al. [115], and security and protection mechanisms in face detection techniques by Fatima et al. [55]. Papers also looked into general smart-home-related topics, i.e., Vasanth et al. [185], who discussed smart home automation and trust-building factors, whereas Michler et al. [124] investigated research work on trust-building factors in consumer IoT products in four areas including smart homes. Reviews also considered alternative approaches to different security issues in a home network such as utilizing fog-computing architecture [151], smart home safety and security using the Arduino platform [159], and using software-defined networking (SDN) [17] to control home network security.

3.2.2 User Perspectives. We identified 10 papers that reviewed the literature on privacy and security issues from home users’ perspectives. Out of all 10 papers, Howe et al.’s [80] research was the only paper that touched upon many of the areas we wanted to review, although it is a very old review (2012). This research focused on the psychology and factors influencing users’ security behaviors and decisions. It explored various demographic characteristics, information sources for home users, users’ understanding of security risks, their perception of security behaviors, and defensive security actions.

Wilson et al. [191] analyzed 150 relevant papers and organized their findings into three broad themes of (1) growth of smart home from “functional,” “instrumental,” and “socio-technical” viewpoints; (2) users and their use of smart home with the subcategories of “prospective users,” “interactions and decisions,” and “technology in the home”; and (3) challenges in a smart home covering hardware and software, design, and domestication issues. Alotaibi et al. [14] reviewed research work on security awareness and education among home users recommended an individualized approach to provide information to users based on their existing awareness level. Michler et al. [124] analyzed user perception from the angle of trust to understand smart home adoption issues.

Two papers explored elderly users’ prospective on using smart homes. Pal et al.’s [142] systematic review on elderly users’ perspective on smart homes observed that the elderly population has serious security and privacy concerns on the use of smart devices. In another systematic review,
Yusif et al. [198] focused on assistive technology use by older people and noted that 34% of the articles examined recognized privacy as a major concern for the older adults.

The other four papers differed widely in their topic choices. After having systematically reviewed privacy-related papers, Kraemer and Flechais [96] concluded that contextual privacy at home and privacy behaviors were very under-researched areas. The concept of privacy paradox and related studies was covered in two reviews [24, 180]. Li et al. [107] conducted a systematic review to find the motivation, barriers, and risk of smart home adoption from a consumer’s point of view.

### 3.2.3 Threats and Attacks.

We found nine papers reviewing various aspects of security threats and attack types. Abrishamchi et al. [2] discussed different types of side-channel threats in a smart home, giving a categorical view of different devices and system layers in a smart home that leaks private data. Heartfield et al. [78], on the other hand, produced a taxonomic view of the possible cyber-physical threats and their impact on smart homes. Alrawi et al. [16] produced a systematized view of the research literature on the smart home security arena, under four major categories: “device,” “mobile application,” “cloud endpoint,” and “communication.” Papers were further sub-categorized into “Attack vector,” “Mitigation,” and “Stakeholder” and evaluated with 45 IoT devices to identify the research gaps. Researchers also explored the security vulnerabilities by different IoT devices [51] and smart home devices [45]. Batalla et al. [25] classified the security threats in home area network devices by referring to the three-layered approach of the European Union Agency for Cybersecurity (ENISA), i.e., perceptual, network, and application layer attacks and physical attacks. Implantables, wearables, and embedded sensors were another topic of discussion [90], along with security measures in mobile computing [109].

### 3.2.4 Security and Privacy Solutions.

Thirteen papers focused on solutions to specific security and privacy problems in a smart home. Chakraborti et al. [41] reviewed research work on software solutions and embedded solutions in a smart home. Two of the papers [131, 158] reviewed blockchain-based solutions for addressing security and privacy problems of a smart home. Three papers focused on different areas of smart home solutions, including current fog-based literature [151], research on SDN [17], and smart home safety and security systems focusing specifically on the Arduino platform [159]. Kuyucu et al. [99] reviewed papers on both issues and solutions. We found six papers reviewing the existing literature on authentication schemes and various security threats to them. Four papers [11, 62, 127, 133] provided a general classification of different authentication schemes, threats, and attacks on IoT devices in a smart home. Others such as Ghazali and Zakaria [66] extensively reviewed the biometric factors reflecting on the authentication mechanisms inside a smart home, whereas Gupta et al. [75] focused on a comparative study of different encryption algorithms used in IoT platforms and proposed solutions to increase the energy efficiency of various systems.

### 3.2.5 Smart Home Devices.

Nine papers covered in the meta-review focused on smart home devices without looking at the system- or user-level aspects where multiple devices form a home network. Varghese and Hayajneh [184] reviewed research on the security and privacy of different categories of smart home devices. Ray et al. [152] provided an in-depth discussion on IoT-based biosensors. Four other papers covered other specific areas including smart TV [10], hybrid broadcasting broadband TV (HbbTV) techniques [67], video surveillance methods [35], implantable and wearable medical devices, and detectors and control systems such as temperature sensors or smoke detectors [90]. Edu et al. [54] reviewed research work on smart home personal assistants (SPAs) to examine the main security and privacy issues, features that characterize known attacks,
and limitations of countermeasures. Features and challenges of smart gateway systems [194] and assisted smart home technologies for elderly people [69] are two other areas of discussion under this category.

3.2.6 Discussions and Research Questions Identified for the SLR. The meta-review led to several key findings.

- First, although 10 papers covered user perspectives in different ways, the discussions have not considered papers from both the security and privacy angle. The reviews have reflected on the privacy issues [96, 180], educational awareness [14], and general challenges users face with very little focus on security and privacy [191]. The “User Perspective,” as discussed in Section 1, comprises a much broader domain. Only Howe et al. [80] discussed more comprehensive details of user perspectives including behaviors and practices of users, but the study is relatively old (published in 2012). There is therefore a need for collating and synthesizing more studies in this growing area.

- Second, 42 review papers collectively cover different aspects of smart home research, including specific (types of) smart home devices, privacy and security issues, and technical solutions. We noticed the absence of wider discussions and a more holistic view of a smart home where multiple and heterogeneous devices are interacting with each other and home users.

- Third, as reported in [96], contextual aspects of the security and privacy of home networks have been much less studied.

- Fourth, among the 10 review papers covering user perspectives, demographic factors are mentioned in only one early review conducted by Howe et al. [80].

- Fifth, although not a systematic review, Howe et al. [80] conducted a very comprehensive review of papers covering user perspectives published before 2010 and was a main motivation of our study. Hence, this work focuses on papers published since 2010.

Based on the above findings, we decided to define the following more focused research questions for the SLR in the second stage of our work, as presented in Table 4.

As is evident from the paper, the boundary between RQ3, RQ4, and RQ5 is not a clear-cut one. Broadly speaking, RQ3 focuses more on the knowledge of home users on facts related to security and privacy matters in the home networking context; RQ4 focuses more on home users’ concerns (i.e., perceived risks and problems), including not only concerns caused by awareness of genuine security and privacy issues but also those caused by false perception or misunderstanding of (possibly non-existing) security and privacy issues; and RQ5 looks more at what home users actually do (behaviors and practices) and the reasons behind them (attitudes, motivation, perception). RQ5 has a broader scope and may be argued to include RQ3 and RQ4 as two sub-questions, since actual behaviors and practices may also be caused by (lack of) awareness and/or concerns.

4 SYSTEMATIC LITERATURE REVIEW (SLR)

The SLR was conducted in line with the nine research questions identified via the meta-review reported at the end of the previous section, examining related original (i.e., non-review) research work in the literature from 2010 to 2021. There are two reasons we decided to exclude papers published before 2010. First, we wanted to focus on more recent research (the past decade), which is a common practice for SLRs [89, 182]. Our results showed that relevant research was indeed more done in the past several years (see Figure 2). Second, Howe et al.’s review work [80] conducted in 2012 covered original research papers published before 2010 quite comprehensively.
Table 4. Research Questions (RQs) Identified for the Follow-up SLR via the Meta-review

| RQ  | Question                                                                 |
|-----|---------------------------------------------------------------------------|
| RQ1 | Has the current literature paid attention to the security and privacy perspectives of users within a home network in a holistic manner? |
| RQ2 | Is there any research exploring home users’ perspectives on security and privacy of multiple inter-connected devices in a home network? |
| RQ3 | What is the current research on users’ awareness of security and privacy issues of a home network? |
| RQ4 | To what extent have researchers explored the security and privacy concerns of users in a home network? |
| RQ5 | What type of user security behaviors and practices in a home network have been researched? |
| RQ6 | What research has been conducted to understand the difference in users’ security and privacy behaviors and practices in a multi-user home network? |
| RQ7 | What demographic factors have been studied while exploring home users’ perspectives on security and privacy aspects in a home network? |
| RQ8 | How have different contexts of a home network been considered when studying home users’ perspectives regarding security and privacy aspects? |
| RQ9 | What theoretical and conceptual frameworks have been proposed and used to facilitate studies on user perspectives regarding security and privacy aspects of a home network? |

4.1 Methodology

As mentioned in Section 2, we followed the same PRISMA method [128, 140] for the SLR, following the exclusion and inclusion criteria explained below. Similar to what we did for the meta-review, we also considered the term “home” in a broader sense.

4.1.1 Exclusion Criteria. Papers meeting the following exclusion criteria were excluded:

- Papers published before 2010.
- Non-English papers.
- Papers that are not related to a home network context or do not include a significant coverage of home networks.
- Papers that do not cover any security or privacy aspects.
- Papers that do not cover home user issues.
- Papers that have been considered in the meta-review reported in the previous section, or papers that do not report original research work.

4.1.2 Inclusion Criteria. Any topics that meet at least one of the relevant areas in the RQs listed in Table 4.

4.1.3 Information Sources and Search Strategy. As mentioned for the general methodology in Section 2, the same three databases, i.e., Scopus, ACM Digital Library, and IEEE Xplorer, were used to search for related research papers. The scope of our SLR was decided mainly by the results of the meta-review, which are reflected in our research questions in Table 4. The research questions that were formulated as the result of the meta-review guided the process of keyword selection. The search queries we used for the SLR are formed by four required sets of keywords, each covering a different aspect of our RQs: the context of a home network or smart home, security or privacy, users, and behaviors (see Table 5).
Table 5. Keywords Used in the Search Queries of the SLR

| (Home AND (Network* OR Smart OR Comput* OR Internet OR Device)) | AND | (Security OR Privacy) | AND | (User OR Human OR People OR Customer OR Person) | AND | (Perception OR Awareness OR Concern OR Behaviour OR Behavior OR Worry OR Action OR Decision) |
|---|---|---|---|---|---|---|

Fig. 2. Number of papers published yearly between 2010 and 2021.

4.2 Results

4.2.1 Papers Selected. The papers returned from the database searches totaled 2,521 from Scopus, 61 from ACM Digital Library, and 424 from IEEE Xplore. After removing duplicates, those papers were first screened based on their titles and abstracts by applying the exclusion criteria. This resulted in 226 papers eligible for more detailed screening and selection based on their full text. This led to the exclusion of 124 papers, and 102 eligible papers were selected.

We performed an additional snowballing-based process [65] to identify more relevant papers by analyzing references of the 102 papers selected. Any potentially relevant papers identified went through the same exclusion and inclusion criteria. In total, 24 additional papers were identified following this snowballing process, increasing the number of selected papers to 126. The results of the process of searching for and identifying the final selected papers are shown in Figure 1.

4.2.2 Yearly Trend of Selected Papers. Figure 2 demonstrates the yearly trend of selected papers in the past 11 years (2010–2021). As can be seen, the majority of papers were published after 2016, indicating the fact that related research has gained momentum toward the second half of the 2010s. This trend is not surprising given the fact that smart home devices have become more popular more recently, and privacy and security issues around them have become more prominent in the past a few years.

4.2.3 Thematic Analysis of Selected Papers. In order to answer the nine RQs defined for the SLR, we conducted a thematic analysis of all selected papers and classified them into nine topical themes each corresponding to an RQ, as shown in Table 6 (2016–2021) and Table 7 (2010–2015). Considering the overlaps between RQ3, RQ4, and RQ5, we mapped selected papers to them as follows: papers that explicitly refer to home users’ understanding, awareness, perception, knowledge, and belief on security and privacy matters in the context of a home network were categorized under RQ3; papers that have an explicit coverage on home users’ concerns or worried on security and privacy issues and problems were categorized under RQ4; and papers that cover home users’ actual security and privacy behaviors and practices were categorized under RQ5. Comparing papers published in the past six years (2016–2021) and the earlier six years (2010–2015), we can see two revealing patterns: (1) research on related topic has been increasing drastically recently since 2016, and (2) recent papers frequently cover multiple RQs compared to earlier papers, indicating that more researchers realized the complexity of security and privacy issues of home
Table 6. Categorization of Papers into the Nine RQs (2016 - 2021)

| Period                  | Paper(s)     | RQ1 | RQ2 | RQ3 | RQ4 | RQ5 | RQ6 | RQ7 | RQ8 | RQ9 |
|-------------------------|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2016–2021               |              |     |     |     |     |     |     |     |     |     |
|                         |              | 1   | 5   | 34  | 46  | 63  | 16  | 17  | 8   | 21  |

- ● Substantial Coverage, ○ Partial Coverage, ◇ Light Touch.
networks and the need to study them from multiple angles. We represented the inclusion of this complexity in the included papers by the following specific graphic symbols: (a) “Substantial coverage” – to represent papers that provided a substantial coverage of one RQ, (b) “Partial coverage” – when a part of the paper is devoted to one RQ, and finally (c) “Light touch” – where a paper discussed an RQ only briefly. Discussions for each RQ mainly concentrated on the papers that provided full coverage, while mentioning the partial coverage. Across all papers published in the 11 years our SLR covered, we can see some popular research areas (e.g., RQ4 “Privacy concerns,” RQ5 “Security behaviors and practices,” and RQ9 “Theoretical and conceptual frameworks”). In addition, the results also revealed some obviously less studied areas, especially under RQ2 on multiple inter-connected devices and RQ8 on contextual aspects.

For each RQ, we will discuss the relevant papers covered in our SLR with greater detail later, grouping them into different sub-categories within each RQ. Table 8 shows an overview of all the papers that have been mapped to the RQs and the sub-categories within each RQ.

4.2.4 RQ1: Holistic View. For this RQ, we considered 11 papers that examined the security and privacy of home networks from a more holistic point of view.

Papers in this category discussed different aspects, including privacy and security risks of users while adopting smart devices at home [22, 110, 141], general challenges for home users and solutions [37], comprehensively assessing privacy risks of smart homes by investigating the data-collecting capabilities of their integral components and assessing the individual risk they pose [170], general benefits and risks [113, 191], the role of trust [56, 162], and the hybrid nature of modern smart homes [34, 136, 201]. The last two aspects are of particular interest for RQ1, so we briefly introduce the five papers below with greater detail.

The role of trust: Ferraris et al. [56] explored the trust relationship between the user and popular smart devices and suggested an interesting trust model, which would enhance home security in regards to how devices interact with users and other devices. Schomakers et al. [162] discussed how the degree of automation can affect the privacy and trust perception of smart home users by not only exploring privacy from the information security viewpoint but also reflecting on the physical, social, and psychological dimensions.

The hybrid nature of modern smart homes: Zhao [201] reflected on the legal definition for the current digital home that has a fluid boundary and discussed some rising problems such as the changing perception of the home’s location, the increasing significance of data protection in the home, and the weakening legal enforcement owing to the “cross border data flows” and “complicated industrial supply chain.” Nthala and Flechais [136] investigated data security decisions in the home and proposed to study them by considering the home space in three distinct
areas: social, activity-based, and technological spaces. Boussard et al. [34] proposed the concepts of “vPlace” and “vSpace” to address the problem of proliferation of poorly secured IoT devices at home. “vPlace” is the collection of all registered resources in the home network and external devices owned by home users along with their dynamic states of connection to the network of connected or not connected to the network, and “vSpace” refers to virtual spaces or rooms oriented toward different contexts of family, work (from home), or visitors.

Some recommended solutions proposed in research falling into this category are interesting, such as calculating privacy risks from the data collection capabilities of a device and dividing the whole home network into physical and virtual places. However, we felt that research should...

Table 8. Taxonomic View of the Research Papers under Different Sub-categories Belonging to the RQs

| RQ                  | Sub-category                                                                 | Paper(s)                                                                 | # |
|---------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------|---|
| RQ1: Holistic View  | Smart device adoption                                                      | [22, 110, 141]                                                           | 3 |
|                     | General challenges and solutions                                            | [37]                                                                     | 1 |
|                     | General benefits and risks                                                 | [113, 191]                                                               | 1 |
|                     | Data flows and privacy risks                                               | [170]                                                                    | 1 |
|                     | The role of trust                                                          | [56, 162]                                                                | 2 |
|                     | Hybrid nature of modern smart home                                         | [34, 136, 201]                                                           | 3 |
| RQ2: Multiple Devices | Lack of common authentication techniques                                  | [7]                                                                      | 1 |
|                     | Multi-device and multi-user scenarios                                      | [34, 166]                                                                | 2 |
|                     | Multi-device privacy configuration                                         | [119]                                                                    | 1 |
| RQ3: User Awareness | Effect of workplace training                                               | [88, 97, 121, 176]                                                       | 4 |
|                     | Privacy awareness and perception                                           | [27, 31, 53, 58, 67, 95, 116–118, 146, 162, 188, 199, 202]                | 14|
|                     | Smart personal assistants                                                  | [1, 85, 98, 115, 145]                                                    | 5 |
|                     | Different types of home users                                              | [5, 93, 193]                                                             | 3 |
|                     | PrivSec awareness in general                                               | [57, 83, 87, 103, 105, 110, 113, 196, 197]                               | 9 |
| RQ4: User Concern   | Privacy concerns in general                                               | [13, 83, 104, 150, 192, 196, 203]                                       | 7 |
|                     | Concerns with smart speakers                                              | [42, 46, 60, 82, 103, 112–114, 130, 144]                                | 11|
|                     | Reflection on underlying behaviors                                         | [68, 108]                                                                | 2 |
|                     | Parental privacy concerns                                                 | [15, 149, 171]                                                           | 3 |
|                     | Other aspects                                                             | [9, 22, 40, 47, 49, 70–72, 81, 105, 154, 165, 190]                       | 13|
|                     | PrivSec concern in general                                                | [9, 28, 29, 59, 88, 134, 141, 153, 197, 199]                           | 11|
| RQ5: Behavior/Practice | Security practice-related decision                                       | [9, 136–138]                                                              | 4 |
|                     | Management and configuration                                              | [79, 87, 179]                                                            | 3 |
|                     | Security behavior affecting practice                                       | [18, 31, 53, 58, 77, 174, 192]                                         | 7 |
|                     | Personalized approaches                                                   | [57, 186]                                                                | 2 |
|                     | Privacy-specific behaviors                                                | [8, 42, 49, 103, 113]                                                    | 5 |
|                     | Machine-learning-based study                                              | [22, 106, 114, 134]                                                      | 4 |
|                     | Other aspects                                                             | [5, 86, 139, 149]                                                        | 4 |
|                     | PrivSec behavior in general                                               | [4, 47, 58, 61, 63, 68, 70, 84, 98, 100, 103, 105, 114, 116, 118, 123, 126, 130, 134, 135, 141, 144, 146, 150, 164, 167, 173, 178, 181, 183, 187, 195, 200, 202] | 35|
| RQ6: Multi-user     | Bystander privacy                                                         | [4, 28, 29, 48, 119, 197]                                                | 6 |
|                     | Access control and configuration                                           | [63, 77, 84, 119, 200]                                                   | 5 |
|                     | Devices shared by multiple users                                          | [63, 82, 84, 103, 113, 117, 118]                                        | 7 |
| RQ7: Demography     | Gender                                                                     | [61, 104, 123, 135, 189]                                                 | 5 |
|                     | Non-gender demographic factors                                            | [30, 40, 47, 94, 153, 167, 183, 186, 190]                               | 9 |
|                     | Location                                                                  | [81, 100, 164]                                                           | 3 |
| RQ8: Contextual     | Location as context                                                       | [120, 129, 134]                                                          | 3 |
|                     | Device as context                                                         | [20, 77, 105, 112, 122, 173]                                            | 6 |
| RQ9: Theoretical     | Protection Motivation Theory (PMT)                                        | [18, 53, 64, 122, 126, 187]                                             | 6 |
|                     | Extended PMT                                                              | [178, 181]                                                               | 2 |
|                     | Theory of Planned Behavior (TPB)                                          | [56, 72, 195]                                                            | 3 |
|                     | Conceptual Framework                                                      | [59, 92, 104, 108, 141, 143, 144]                                       | 7 |
take into account co-existence of different (both smart and traditional) devices in a home network, exploring whether people’s security and privacy behaviors and actions are different in different types of home networks such as in a student accommodation, an Airbnb, or a shared flat.

4.2.5 RQ2: Multiple Inter-connected Devices. For this theme, we found only a small number of (four) papers [7, 34, 119, 166], which are briefly introduced below.

Al Abdulwahid et al. [7] focused on the unavailability of a common authentication technique using multiple digital devices. Boussard et al.’s [34] vPlace and vSpace concepts, introduced previously for RQ1, utilized the SDN technique to manage access control in a multi-user home network with multiple devices. Sikder et al. [166] discussed the complex and conflicting demands of multiple users in a multi-device home compared to single-user environments and suggested a new access control system called Kratos to enhance awareness of related environments. Marky et al. [119] (lab-based study, n = 15) found that users would prefer to have detailed information about each device, a clear status communication, more dynamic and rule-based settings, and delegation options to adjust privacy settings in a multi-device setting.

The limited research on RQ2 suggests the need for research in the field of interconnections and interactions between multiple home devices and any consequential security and privacy problems.

4.2.6 RQ3: Security and Privacy Awareness of Home Users. Thirty-five papers covered in our SLR studied users’ awareness and perception of security and privacy in the context of home networking, with 24 papers substantially covering this topic.

The effect of workplace training and the subsequent cyber awareness for home users is a topic that has received some attention. While some researchers investigated organizational, social, and personal factors that can affect cyber security awareness of home users and attributed the cyber awareness of the home users to personal initiatives’ knowledge, others such as Talib et al. [176] and Kritzinger and von Solms [97] recommended organized security awareness programs at the workplace to help boost home users’ cyber awareness. Kang et al. [88] and McDermott et al. [121] suggested the absence of a direct relationship between people’s technical background and their security or privacy awareness.

The topic of low privacy awareness is another popular topic discussed by many researchers [53, 67, 116–118, 146, 163, 202], owing to reasons such as the absence of audio-visual inputs [202] or a low level of self-efficacy [146]. On the positive side, it was also reported that home users are willing to engage in privacy protective mechanisms if relevant tools are easy to understand and cheap [53]. Through an online role-playing exercise, Binns et al. [31] (online role playing scenario, n = 27), found that home users’ privacy-related decisions are heavily influenced by their pre-existing perceptions of and relationships with companies (more precisely, mobile app suppliers). They suggested privacy-aware tools that can help users to incorporate such pre-existing contextual factors into their privacy-related decisions. Two studies [27, 95] suggested using augmented-reality-related solutions to make home users aware of privacy issues and to encourage them to make more informed decisions. Wickramasinghe and Reinhardt [188] (survey, n = 229) observed that users had a lack of knowledge of sensitive data collected by smart objects and the third parties receiving such data. Zeng et al. [199] (interview, n = 15) suggested how users’ vulnerability depends on the level of their privacy knowledge and pointed out a clear mismatch between the awareness and power of the owner/administrator of the smart home in comparison to other home users. Freudenreich et al. [58] (interview, n = 16) studied security practices of home users related to Wi-Fi security and found that, although they were mostly aware of the vulnerabilities, they found it difficult to address these issues.

Due to the growing popularity of smart speakers (also called smart/intelligent personal assistants or voice assistants—we will use the shorter term “smart speaker” hereinafter), some
studies [1, 85, 113] looked into different security and privacy aspects of smart speakers. They found that home users were generally aware of personal data being stored on smart speakers, but not with the service provider and in some cases with other third parties. Most users were not even aware that they could review or delete the stored data [113]. The incomplete mental model on different privacy issues [1] or lack of knowledge on the matter [98] leads to various privacy concerns. Park and Lim’s research [145] demonstrated that at times, when users are more aware of their privacy, they expected their own personal space-oriented features in the smart speakers.

Three papers looked at different types of home users. Kim et al. [93] (trend analysis n = 23; interview n = 20; survey n = 188) categorized users into different groups depending on the level of their cyber awareness, for example, “Innocent Irene” (extreme low level of awareness) or “Parental Patrick” (people with a family to protect). They suggested designing smart devices to suit home users’ cyber personality. Xavier and Pati [193] (survey, n = 324) pointed out how lack of awareness affects the ability to understand security threats, whereas Ahmad et al. [5] focused on lack of parental awareness on the topic of cyber threats toward children at home.

Home user awareness and perception were also addressed in nine papers [57, 83, 87, 103, 105, 110, 113, 196, 197] while focusing on other related concepts such as privacy and security concerns, privacy and security behaviors of single and multi-users, and contextual security at home.

Research on RQ3 has a noticeable focus on privacy awareness, possibly because privacy issues of smart devices such as smart speakers are more visible and understandable by home users than (technical) security issues. The research on the effect of workforce training was a topic we did not expect, showing how home and work contexts can be connected. Discussions on user awareness on topics such as issues from the connected home, existing tools and supports to mitigate issues arising, and understanding of home users on legal and economical help available in case of security breaches are surprisingly thin and important areas to focus on.

4.2.7 RQ4: Security and Privacy Concerns of Home Users. RQ4 is one of the most discussed themes, with 47 papers covering a range of related topics and 36 of them focusing majorly on this RQ. The other 11 papers [9, 28, 29, 59, 88, 134, 141, 143, 153, 197, 199] focused more on topics in other RQs such as multi-user concepts or user behaviors, so they will be covered elsewhere.

Seven papers looked at privacy concerns in a broader and more systematic sense. In order to understand the privacy concerns of home users, Zimmermann et al. [203] (interview n = 42) categorized home user concerns under two types, “unrelated to attacks,” such as dependency on a technology or loss of control to use, and “related to attacks,” such as smart home data exposure and manipulation of device sensors. Worthy et al. [192] (experiment, n = 5) collected daily use data from the participating homes with a specially developed IoT device to find that users tend to demand more control over the information collection process when they have less trust in the data controller and consumers. Through an empirical analysis involving 265 valid respondents, Lee [104] (survey, n = 300) observed a positive association between different types of vulnerabilities (“Technological,” “Legal,” and “User”) and IoT privacy concerns, except for provider vulnerabilities. Hwang et al. [83] (survey, n = 300) revealed different levels of privacy risk perception for different types of home IoT services, venturing into a tradeoff between privacy and functionalities. This tradeoff is also re-iterated by a study conducted by Psychoula et al. [150] (survey n = 231; interview n = 41). Yao et al. [196] explored user-centered privacy design (co-design study, n = 25) to demonstrate home users’ conceptualization of privacy control mechanisms. They identified six factors (“Data Transparency & Control,” “Security,” “Safety,” “Usability,” “Contextual detection & Personalizing,” and “System Modality”) to help design smart home privacy controls. A study [13] focused on understanding Saudi home users’ privacy and security concerns of using smart devices.
and revealed that 79.7% of Saudi users were afraid of losing their data because of low awareness of related issues and lack of governmental interventions.

Eleven papers discussed privacy concerns on smart speakers, the most popular topic under RQ4, and discussed it from many angles, i.e., lack of privacy concerns by users, contextual privacy concerns, data collection behaviors of the manufacturers, and underlying behaviors such as trust and psychological factors. Lau et al. [103] conducted a diary study with 34 smart speaker users and non-users to find that smart speaker users lacked knowledge on privacy risks, whereas non-users lacked trust in the vendors. This was further highlighted by Malkin et al. [113] and Chalhoub and Flechais [42], who commented on how users preferred comfort to privacy because of the low level of privacy concern and that any desire to observe privacy behaviors is inhibited by the lack of a user-friendly interface. Concerns about the privacy risks that smart speakers can track and listen to users’ data were observed in two studies [46, 85]. Fruchter and Liccardi [60] used different natural language processing (NLP) tools to process 109,536 online user reviews on Amazon Echo and Google Home for the presence of specific security- and privacy-oriented keywords. Only 2% of the reviews using those keywords showed major concerns about data collection. Manikonda et al. [114] examined online reviews to note users’ positive outlook toward the smart speakers and a good level of privacy. Mols et al.’s explorative study (survey, n = 325; focus group, n = 35) on Dutch households’ privacy concerns [130] provided a multi-dimensional understanding of users’ concerns including surveillance, device security, day-to-day user behaviors, and transparency of platforms. Lutz and Newlands [112] (survey, n = 325) discussed privacy concerns related to smart speakers from a contextual perspective, suggesting that such concerns vary depending on the source. Two papers focused on users’ concerns about the data collection behaviors of smart speaker manufacturers. Huang et al. [82] investigated shared use of smart speakers (interviews, n = 26) and observed that participants expressed privacy concerns about their housemates and visitors, and also about privacy-invasive data collection by speaker manufacturers. Park et al. [144] (survey, n = 359) noticed that privacy concerns led to negative privacy-coping behaviors such as anger, anxiety, and disappointment against the relevant companies and generated bad word of mouth or disengagement.

Reflection on the underlying behaviors such as psychological mechanisms and trust behind users’ concerns about smart speakers was explored in two papers. Liao et al.’s investigation (survey, n = 1,160) on the role of privacy and trust in users’ decisions on adopting smart speakers [110] revealed that users tend to trust the vendors (Google, Amazon, and Apple) on the usage of their information, and privacy concerns differ between people who use different hardware devices (a smartphone or a smart speaker) to interact with the agent. Ghosh and Eastin [68] (survey, n = 289) examined different psychological mechanisms underlying home users’ interaction with software agents such as Alexa and Siri and hardware devices such as smart speakers and smart phones, and how they affect privacy concerns and information disclosure behaviors. This is similar to what Ghosh and Eastin’s [68] study explained about how participants are more likely to report higher privacy concerns when interacting with voice assistants through smart speakers than through smart phones.

Parental privacy concern was discussed in three papers. Reflecting on parents’ technology usage, control, and concerns, Alqhatani and Lipford [15] (interview, n = 20) stated that parents did discuss children’s privacy and security concerns regarding their online use and controls but did not expand on these to include smart devices. In contrast, Prasad et al. [149] (interview, n = 20) considered parental privacy concerns toward service providers and manufacturers and how they affect their children. Sun et al. [171] (interview, n = 23) identified six factors that, according to them, influence parents’ perception of privacy risks, including parenting style, tech-savviness, trust in manufacturer, age of the children, features of the used devices, and news media reporting.
Twelve papers considered other aspects that might affect privacy concerns of home users. Golbeck [70] analyzed 501 online comments to find out that 81% of the home users have concerns about using their Internet Service Providers’ (ISPs) supplied home router as a public Wi-Fi hot-spot. Privacy concerns were found to be the most prevalent ethical concern in a study (survey, n = 631) by Seymour et al. [165]. Through their study on authentication management techniques of home users (n = 93), Alam et al. [9] revealed that this type of privacy concern does not actually reflect users’ practices. Grünwald and Reisch’s [71] study (survey, n = 701) revealed that participants were more inclined to share their location data for services (50%) than with service providers (28%), but struggled with differentiating between the two. Lee and Kobsa [105] conducted a clustering analysis based on data collected from 200 participants on 2,800 hypothetical IoT scenarios and five contextual parameters (“where,” “what,” “who,” “reason,” and “persistence”) affecting home users’ privacy concerns, to find scenarios according to their privacy risks. A new theoretical model (which will be discussed more in RQ9) was suggested by Guhr et al. [72] to find out the role privacy concerns play in home users’ acceptance of smart home technology. Results of Crabtree et al.’s research [49] demonstrated the fact that the discussion and design efforts for any sort of privacy mechanisms should focus on managing human relationships rather than controlling data flows. Both Barbosa et al. [22] and Cannizzaro et al. [40] commented on users’ reluctance on home IoT adoption due to their privacy concerns, and how such reluctance grows with age [40]. Devices and platforms other than smart devices such as ambient assisted living (AAL) [47] and mobile-assisted robots [154] were also studied to understand the type of privacy concerns they might generate. Wilkowska et al. [190] used three different methodologies, i.e., a focus group (n = 42), a survey (n = 104), and an experimental usability study (n = 55), to study home users’ privacy concerns in the context of AAL and found that the level of privacy concerns of participants observed following each methodology differed significantly.

Finally, one paper paid attention to the role of cultural background in privacy concerns: Huang and Wu [81] conducted a small interview study with nine Chinese smart home users, showing some preliminary evidence regarding their privacy concerns likely being less than an average American user (based on past American privacy-related studies).

Multiple papers related to RQ4 focused on a specific type of smart device—smart speakers. The tradeoffs between privacy and functionality, how privacy concerns affect the decision of smart home adoption, are also relatively popular topics of discussion. However, we found that some smart home devices such as smart home appliances are much less studied, despite the increasing use of these devices in modern smart homes.

4.2.8 RQ5: Security and Privacy Behaviors and Practices of Home Users. This is another popular area of research, with 66 papers. Some papers (32) focused majorly on this RQ and others (34) reflected on security and privacy behaviors while discussing other concepts such as privacy concerns, awareness, multi-user issues, and related conceptual frameworks [4, 47, 58, 61, 63, 68, 70, 84, 98, 100, 103, 105, 114, 116, 118, 123, 126, 130, 134, 135, 141, 144, 146, 150, 164, 167, 173, 178, 181, 183, 187, 188, 195, 200, 202]. Here, we will focus on the 32 papers in the former group.

Security-practice-related decisions were discussed in four papers. Nthala and Flechais [136] in their study (interview, n = 15) identified four themes (stimuli (cues to action), support, stakeholders, and context) around home users’ security-practice-related decisions. In a follow-up work (interviews, n = 50) [138], they found that home users majorly rely on family and friends as an informal support network. Furthermore, in another follow-up work (survey, n = 1,128; interview, n = 65) [137], they found that security practice is affected by survival/outcome bias, factors undermining confidence in a security measure, and other well-known factors such as trust, cost,
knowledge, and skill. Alam et al. [9] observed that despite being very concerned about their privacy and security, users don’t follow appropriate security steps.

**Management and configuration of smart devices** were explored in three papers. Kaaz et al. [87] (experiment, \( n = 7 \)) found that, contrary to popular belief, smart devices are not “plug and play” and a majority of home users face multiple barriers while configuring such devices, which often force them to accept vendors’ default (possibly flawed) security and privacy settings. Ho et al. [79], in an earlier (2010) study on home wireless networks, revealed how home users depended on out-of-box security tools provided by manufacturers, hardly changed the default security settings, rarely installed and maintained encryption keys across devices, and did not perceive any differences between encryption and access control. Topa and Karyda [179] collected and analyzed a broad spectrum of privacy and security issues on the usability of security tools such as VPNs and anti-virus and anti-spyware programs (scenario based, survey, \( n = 150 \); interview, \( n = 112 \)) to highlight the need for detailed help, consistency regarding use of technical terms, concerns over the use of personal data, and the absence of appropriate usability tools for disabled users.

Seven studies looked at **security behaviors affecting home users’ security practices** for home networks. Anderson and Agarwal [18] observed (survey, \( n = 600 \)) that home users’ security behaviors were influenced by cognitive, social, and psychological components and hence, all such factors should be considered when analyzing their security attitudes. He et al. [77] (survey, \( n = 425 \)) confirmed a proposed hypothesis that participants focused on IoT devices’ capabilities rather than the devices themselves to define access control and authentication policies. Binns et al. [31] concluded that home users’ security actions are mostly influenced by their preconceived notion about the company responsible for the specific hardware device or software (e.g., a mobile app). However, Dupuis and Ebenezer [53] were of the opinion that home users would be more willing to take precautionary actions if they clearly understand the security mechanisms of the products they use. Via a mixed-method study (survey, \( n = 1,006 \); interview, \( n = 14 \)), Taieb and Pelet [174] observed that home users’ attitudes and perceptions toward IoT devices and the security of their data depend on the device type; e.g., a smart health device could induce them to share more information than a smart speaker. Worthy et al. [192] conducted an experiment to collect data from five different households for a period of 10 to 14 days and analyzed the inhabitants’ behaviors. They observed that the participants became familiar with new devices very soon and were generally happy with sharing data as long as it is properly de-identified (e.g., via aggregation) and they were aware of the purpose of collection. Risks associated with Wi-Fi vulnerabilities in home users were explored by Freudenreich et al. [58] (survey and interview, \( n = 16 \)), who found that, although generally aware of the privacy risks, people were not knowledgeable or skilled to address such problems.

**The need for personalized approaches** is highlighted in some work. Both Wash and Rader [186] and Forget et al. [57] argued on the unsuitability of a “one size fits all” approach to security. Wash and Rader [186] discussed different “folk models” of threats that induce a home user to make different security decisions according to their contextual belief. Forget et al. [57] collected user security behaviors and machine configurations of 73 users for at least 3 months within a 9-month time window and then interviewed 15 users out of the 73. Their results reiterated a finding of Wash and Rader [186]—since home users engage in security behaviors and practices differently, they may benefit from different styles and different levels of interventions for their specific needs.

**Privacy-specific behaviors** of home users were explored in several papers. Crabtree et al. [49] studied the digital practices of 20 homes in the UK and found that participants employ a number of “fine-grained methods” (throwaway emails, ad blockers, cookies, consent forms, private browsing) to manage the flow of their private data securely. Chalhoub and Flechais [42] investigated home users’ attitude in terms of the **user experience (UX)** and pointed out that the lack of users’
privacy concerns arose out of their individual perception of the situation and how they traded their privacy needs for the benefits from smart devices. Lau et al. [103] and Malkin et al. [113] found no evidence of privacy-seeking behaviors in users of smart speakers and observed that users did not use privacy controls already available to them in such devices. Al-Ameen et al. [8] revealed a number of mismatches between users’ actual perception of data collection and data sharing by the IoT devices compared to the devices’ published privacy policies.

Four papers used **machine learning (ML) tools** to reflect on home users’ privacy or security behaviors. Naeini et al. [134] used ML classifiers to predict users’ preferred comfort level and their decision to allow or deny specific data collection, whereas Barbosa et al. [22] implemented a decision tree classifier to suggest how easy affordability as a “motivator” can defocus privacy as a “blocker.” Manikonda et al. [114] applied the **latent Dirichlet allocation (LDA)** algorithm [32] and Word2Vec [125] to understand users’ privacy behavior and concerns. Li et al. [106] analyzed home users’ security and privacy behavior by examining 15.4 million video streams from 211k Chinese users and observed that frequent use of the camera increases the privacy risks.

Four papers looked at **other aspects** of user attitudes, perceptions, and behaviors. Prasad et al. [149] discovered (focus groups, n = 3; interviews, n = 14) that parents did not trust device/software manufacturers or ISPs to protect their children from harms when using smart devices and felt it was their responsibility to do so. Jin et al. [86] discussed a different topic of residential privacy by examining data collected from the Foursquare application and identified several vulnerabilities and privacy risks caused by user behaviors. Oulasvirta et al. [139] used a specific **behavioral observation system (BOB)** to pool sensor data from designated surveillance devices (Wi-Fi cameras, key-presses from personal computers, smart devices, TV and DVD media centers) to comment on the contextual behavioral change. Abrokwa et al. [3] (survey, n = 493) observed no significant privacy behavioral differences between users of two mobile operating systems (iOS and Android).

The RQ5-related papers cover a wide range of topics, e.g., home users’ privacy and security behaviors, practices and decisions, and parental behaviors, which mostly focused on issues around standalone devices. As in the case of RQ3 and RQ4, more future research should focus on understanding **home users’ behaviors and attitudes in a connected home with hybrid devices**.

### 4.2.9 RQ6: Multiple Users in a Single Home.

Eighteen papers in our study covered security and privacy issues in a multi-user home environment, in different levels of depth.

Five papers examined the **privacy of bystanders**, e.g., guests and nannies. Yao et al. [197] examined potential privacy concerns and expectations of the bystanders (focus groups, n = 18) and observed strong contextual variations as they switch their roles under different social relationships. Bernd et al. [29] identified different types of bystanders including nannies, home care attendants, house cleaners, and maintenance workers who can be affected by the use of smart devices but are not directly involved in the use of such devices. In a follow-up study, Bernd et al. [28] (interview, n = 25) found that nannies expected the existence of smart cameras but wanted transparency of information from their employer (i.e., the homeowner) beforehand and were concerned by potential misuse of collected data. Cobb et al. [48] surveyed 386 incidental users of smart devices to understand their most typical concerns and the context where it materializes, and recommended better communication between the primary and incidental users. Ahmad et al. [4] (interview, n = 19) proposed a concept of “tangible privacy” for designing IoT devices to provide stronger privacy assurances to bystanders.

Four other papers discussed challenges in a multi-user home, focusing on **access control and configuration management of home devices by different users** in the same home.
environment. Access control issues in a multi-user home were discussed by three groups of researchers [77, 84, 200], who conducted scenario-based analyses and discussed challenges of using smart devices in a multi-user environment, including coarse-grained access control resulting in either complete access or no access to users and unintended or unintended threats to the primary user’s data. Marky et al. [119] investigated a prototype for a multi-setting interface to adjust privacy settings by multiple users with multiple devices (experiment, n = 15) and found that users prefer the ability to access detailed information with the settings. By exploring security and privacy implications in a multi-user home, Zeng and Roesner [200] designed a prototype with different access control features (i.e., location-based, supervisory). They discovered that factors such as usability and configuration complexity, lack of concerns for devices, interference with other functionalities, and trust between different home users are some of the reasons users ignore access control mechanisms. Four researchers [77, 84, 200] recommended different design changes in smart devices to increase the usability and accessibility of the functionalities to all home users. Additionally, He et al. [77], exploring different types of relationships in a multi-user home ("babysitter vs. visiting family" and "child vs. teenager") found clear differences in different users’ desires to have specific access control policies attached to different capabilities of an IoT device.

Nine researchers discussed the challenges of device use in a multi-user home by primary and secondary users, mostly focusing on the shared use of a smart speaker. Both Malkin et al. [113] and Lau et al. [103] reflected on privacy tensions between primary, secondary, and incidental users of smart speakers, while Zeng et al. [199] pointed out unique privacy and security challenges that occur in a multi-user home where incidental users depend on the primary users’ knowledge and control. In a related study (interview, n = 21), Marky et al. [116] observed that visitors would usually accept the data collection by smart devices so long as the data is anonymized and recommended to gain awareness and knowledge and evaluate data sensitivity, to exert control over their privacy. In a follow-up study, Marky et al. [118] (interview, n = 42) investigated two related privacy issues: privacy of bystanders to homeowners and privacy of homeowners to bystanders. They recommended that the IoT designers must pay attention to both bystanders and the users while designing their devices. In their study on a mental model of 30 participants, Marky et al. [117] noticed a general lack of awareness among visitors about the data flows in a smart home ecosystem. Based on interview data from 26 participants using smart speakers, Huang et al. [82] (interview, n = 26) found that participants had different types of concerns about inappropriate access and misuse of personal information by housemates and other external entities, but would follow the same risk management strategies in both cases. Geeng and Roesner [63] conducted a mixed-method study (n = 18) to study the inter-communication, tensions, and challenges in a multi-user home. They observed that the smart home environment mimics the existing power dynamics (i.e., parent-child) in a household, giving smart home drivers more access to functionalities than other users. Park and Lim [145] discussed the privacy awareness of family members while sharing a smart speaker.

Papers related to RQ6 cover mainly two areas, bystander privacy and access control. Users’ understanding of the more complicated data flows in a multi-user home is one of the main topics that we felt should be studied more, along with other areas such as threats from malicious secondary users and security and privacy implications of interactions between multiple devices and multiple users.

4.2.10 RQ7: Demographic Factors and Their Effects. Seventeen papers in our study substantially covered topics related to this RQ.

Five papers studied home users’ security behaviors, practices, and concerns, with a focus on gender. Wilkowska and Ziefle [189] studied the use of e-health technologies at home (n = 104,
60 females and 44 males), showing that female and healthy adults were more prone to demand stringent security and privacy standards than male adults and ailing elderly, respectively. In contrast, Nohlberg and Kävrestad’s survey (152 participants, 53 females and 99 males) [135] found men to be more decisive in comparison to women in an information security decision. McGill and Thompson [123] surveyed 624 users (234 females and 390 males) and their results echoed Nohlberg and Kävrestad’s finding that security behaviors of female users are weaker than male users’. Furini et al. [61] conducted a small study during the 2020 COVID-19 lockdown on people’s privacy behaviors and concerns on smart speakers, and found that both male and female users had privacy concerns. Looking into gender and IoT use experience, Lee [104] concluded that female users were more concerned by their own vulnerabilities, and people without technical experience were more concerned by providers’ vulnerabilities.

Some other papers focused on demographic factors beyond gender such as age and disability while analyzing privacy and security attitudes and concerns of people using AAL, older adults, and other variables such as age, ethnicity, income level, and disability. van Heek et al. [183] studied the acceptance of AAL technologies and the tradeoffs between perceived benefits and barriers (survey, \( n = 279 \)). They found that user diversity in terms of age, disability, and caregiving experience does significantly affect the tradeoffs between perceived benefits and barriers. In another related study that used three different methodological approaches (focus groups, survey, and a usability study), Wilkowska et al. [190] noticed that privacy with regard to AAL technologies is independent of age or gender. The same conclusion was also drawn by Choukou et al. [47], who compared the attitude of older and younger adults on the use of AAL technology. However, when age was discussed as a factor influencing privacy and security attitudes in general (not specific to AAL), it tends to play a significant role in user attitude. Age was a parameter studied by Singh et al. [167] (survey, \( n = 231 \)), who found that older adults (36–70) were more willing to share data on health grounds than their younger (below 36) counterparts. In their analysis of a large-scale survey with 2,033 UK participants, Cannizzaro et al. [40] noticed that age and education level play a significant role in determining people’s trust in IoT devices for security and privacy. In another study, Wash and Rader [186] found that educated users and older adults often exercise fewer precautions in regard to security threat. Klobas et al. [94] reported similar results about security perceptions of older and educated participants who seemed to be more likely to assess security risks of IoT products and had a more positive attitude toward them, although they were still concerned about the privacy and functionality, which does not meet the needs of their specific requirements [30]. Reeder et al. [153] interviewed 10 post-menopausal women (age band: 50–70) to understand their perception of wearable devices and found that the participants largely accepted the technology as useful.

Seidl et al.’s [164] study (survey, \( n = 214 \)) found that geo-privacy behaviors are very much linked to a participant’s underlying knowledge of the field and similar across different demographic factors including gender, ethnicity, and income level. Huang and Wu’s [81] comparative study on Chinese and US users revealed that users’ privacy concerns in China seemed to be lower than in Western countries. Lafontaine et al. [100] conducted a survey (\( n = 232 \)) over three geographic regions (the US, the EU, and India) and found that IoT users were comparatively more comfortable in accepting risk than non-IoT users. Furthermore, they observed contrasting behaviors of users in different regions; i.e., people in India trust their government more in protecting their data compared to people in the US and the EU.

Papers related to RQ7 studied demographic factors such as gender, age, educational background, disability, ethnicity, and income level and their implications on security and privacy behaviors of home users. There is contradictory evidence of weaker security behaviors of females compared to males, therefore needing more research in this area. We noticed that a majority
of the studies focused on developed nations such as the UK, the US, and the EU, so more research on developing countries and non-Western countries is much needed.

4.2.11 RQ8: Contextual Factors Influencing Security and Privacy Behaviors and Practices at Home. Eleven papers in our study contributed substantially to this theme.

Three papers considered location as the contextual factor. McCreary et al.’s [120] study (video experiment, n = 264) found that people were very much concerned about privacy inside their home regardless of the activities they are involved in compared to outside their home. Molina et al. [129] (survey, n = 276) asked their participants to imagine using Wi-Fi networks at four different locations (coffee shop, university, Airbnb, and home). One of their hypotheses is that a higher belief in the publicness heuristic can lead to less information disclosure. Their results showed positive evidence to support this hypothesis. Naeini et al.’s [134] research (vignette study, n = 1,007) working with a set of 380 IoT data collection and different scenarios revealed the context dependence and the diverse nature of privacy preferences of home users.

Other researchers analyzed contextual use of devices [139] affecting privacy and security behaviors or leading to specific individual knowledge and experience or a device’s primary function dictating users’ privacy perception [4]. Lee and Kobsa [105] conducted a comprehensive analysis using K-mode clustering analysis, employing data from hypothetical IoT scenarios (survey, n = 200). They used K-modes clustering analysis with four clusters (“Very unacceptable,” “Unacceptable,” “Somewhat acceptable,” and “Acceptable”) and analyzed the data with five contextual parameters (“where,” “what,” “who,” “reason,” and “persistence”) to reflect on the impacts of contextual factors on people’s privacy perceptions. Apthorpe et al. [20] used the contextual integrity (CI) framework (survey, n = 1,731). They collected 3,849 information flows passing between various first- and third-party recipients in a smart home to provide rich insights into why device manufacturers should survey privacy norms in specific contexts and why privacy norms should support restrictive rather than permissive IoT device communications. Tabassum et al.’s [173] study (interview, n = 23) discovered that users’ threat modelling of their home and their protection behaviors were not shaped by their existing knowledge, but by their experience in other computing contexts. McGill and Thompson’s research (survey, n = 629) on users’ security behaviors [122] revealed that users perceived to expect more risks from the use of a mobile device than from a home computer. He et al. [77] studied access control issues in multi-user homes (n = 425) and looked at frequent context-dependent capabilities of various IoT devices. They noticed five contextual factors (“Age,” “Location of Device,” “Recent Usage History,” “Time of Day,” and “Location of User”) impacted significantly on the implementation of access control capabilities of smart devices. According to Lutz and Newlands’s study [112], privacy concerns are dependent on the context of the origin source.

The major areas of discussion on this RQ were location and use of smart devices. However, we feel that some other important contexts need more research, including varying security behaviors and practices of home users when using traditional devices versus smart devices, sharing a particular device with other users, and different types of smart devices other than more studied ones such as smart speakers. There is also a lack of research on the legal context, e.g., home users’ understanding of the legal support available to them in case of any security or privacy breaches, and their legal rights when it comes to the storage and manipulation of their data on different types of home devices.

4.2.12 RQ9: Theoretical Frameworks of Security and Privacy Behaviors. With 18 papers in our dataset, RQ9 is another much-discussed theme in our study.

Seven papers in this theme [18, 53, 64, 94, 122, 126, 187] discussed users’ security behaviors in light of the Protection Motivation Theory (PMT) [156]. Analyzing the survey data from
72 home computer users, Mills and Sahi [126] concluded that participants were not significantly influenced by perceived vulnerability or perceived severity when trying to implement additional security measures on their home computers. However, they identified that response efficacy and self-efficacy were moderate predictors of individuals’ intention to implement additional security measures. Klobas et al.’s [94] study on security risk’s influence on smart home adoption (survey, n = 405) observed the perceived risk as a determinant of smart home adoption intentions. White et al. [187] used a survey with 945 adult participants to investigate different factors that affect computer security protective behaviors and perceived security incidents. Dupuis and Ebenezer [53] used a mixed-method study under the framework of PMT, using analysis of data from 500 customer reviews of 10 IoT devices, 18 interviews, and a large-scale AMT-based online survey with 1,006 valid responses, to study the lack of privacy-risk awareness. They found that home users would engage in different privacy-protected mechanisms if they are simple to understand and cheap to use. George et al. [64] reiterated this fact in their survey (n = 219) when they found that low awareness of risk coupled with self-efficacy hinders the users from addressing the existing privacy risks. Anderson and Agarwal [18] used PMT to examine security behaviors of 101 participants in a survey with 594 home computer users and an experiment with 101 participants. They concluded that users’ security behaviors were influenced by an individualized message focusing on the benefits of good security behaviors.

Two papers extended the functionalities of PMT for their investigation. Tsai et al. [181] examined how PMT factors predict users’ security intentions (survey, n = 988). They extended the original PMT theory by including commonly neglected variables such as threat susceptibility, prior experience with a safety hazard, and coping self-efficacy to understand threat perspectives of home computer users while being online. They found several factors such as gender, age, threat severity, prior experience, coping self-efficacy, and personal responsibilities, among others, that are significantly co-related with users’ security intentions. Thompson et al. [178] (survey, n = 629) included the social and peer influence, psychological ownership, and metrics on actual behaviors to measure the effectiveness of these factors on user behaviors under different contexts. Their results demonstrated that users behaved differently under both contexts (personal computers and mobile devices). Their findings echoed the PMT by proving the fact that perceived vulnerability, self-efficacy, and response cost all played an important role in determining users’ security behaviors.

The Theory of Planned Behavior (TPB) proposed by Ajzen [6] explains that individuals depend on intention to behave in a certain way and their ability to control that intention. Yang et al. [195] added six external variables to TPB to build a comprehensive new model and validated the model with data collected from 216 survey participants. The results echoed the core concept of TPB that attitude, subjective norm, and perceived behavioral control (PBC) are positively related to behavioral intention of the user. Guhr et al. [72] developed a research model based on several theoretical models, including TPB, to measure the effect of privacy concerns on the smart device usage by home users. The study (survey, n = 256) applied the partial least squared structural equation modeling (PLS-SEM) to identify four essential elements to represent privacy concerns, including secondary use of personal information, perceived surveillance, perceived intrusion, and awareness of privacy practice. Ferraris et al. [56], as suggested in Section 4.2.4, put forward a holistic trust model to improve security at home.

Some other conceptual frameworks include the Technology Threat Avoidance Theory (TTAT) for testing the IT threat avoidance [108], negative-perception modeling for identifying barriers to smart home usage by the elderly user [141], the privacy calculus theory to measure the relationship between perceived privacy risk and the willingness to share privacy information [92], Innovation Resistant Theory (IRT) and Multidimensional Development Theory (MDT) used to examine privacy concerns by Pal et al. [143], and the new model Perceived Surveillance
of Conversation (PSoC) developed by Frick et al. [59] to determine the cause of privacy concerns. Some of the new frameworks include the Stimuli-organisms-responses (S-O-R) framework for measuring the balancing role of negative emotions such as anger, anxiety between privacy concerns and behaviors [144], and the vulnerability-privacy concern-resistance (VPR) framework for explaining how users’ resistance to the adoption of new technology is affected by their privacy concerns and their perception of their vulnerabilities [104].

Although old and new theoretical frameworks have been used/developed to explore home users’ security and privacy attitudes, practices, and concerns, studies on using such frameworks to analyze security and privacy aspects of the use of smart devices such as smart speakers are largely missing from the papers we covered. In addition, it seems that such frameworks have not been incorporated into relevant ontologies to support related research in a more holistic manner.

5 DISCUSSIONS AND RECOMMENDED RESEARCH DIRECTIONS

The results of our meta-review and SLR showed active and extensive research on different topics in the broad area of user perspectives of security and privacy aspects of home networks. However, our work also revealed many research gaps, indicating that more research is still required. In this section, we summarize our core findings around seven recommended future research directions. Note that some can be mapped to a single RQ of our SLR, but others cross-cut several RQs.

5.1 Co-existence of Multiple Connected Devices in a Single Home

As mentioned in the Introduction section, the average number of connected devices in an average household in most Western countries is over seven [101]. The existence of many households with multiple home devices calls for more research on the role of co-existence of multiple devices in a single home. Such needs have been met by some research [34, 166], but with limited depth and breadth. We observed three main research gaps. First, most research that has been conducted focused on standalone devices or a specific type of device such as smart speakers [1, 42, 46, 145], smart phones [40], and activity sensors [153]. Although recent research has explored multiple devices in a connected home, especially data flows in a connected home [36, 39, 91], more research is still needed to investigate how different types of home devices interact with each other, e.g., a smart doorbell with a smart alarm, how such interactions are perceived by the users, and how they affect the security and privacy of the home network as a whole. Second, the increasing number of home devices in a single home will unavoidably complicate configuration and management of such devices, including their security and privacy settings. Third, a large number of studies have concentrated on specific types of home devices, leaving some types of home devices under-studied, especially different types of smart appliances. However, the use of smart appliances in homes has been steadily increasing [102, 169], so more research on such devices is much needed.

5.2 Multiple Users in a Single Home

According to the Population Reference Bureau (PRB) [148], the average household size worldwide in 2020 was 4.0, suggesting that most home networks have multiple users. Considering frequent and occasional visitors (e.g., neighbors, relatives, friends, carers, and nannies) to a household, the number of users can be even larger. There are also more complicated scenarios where the concepts of “home” and “regular occupants” are not clearly defined. For instance, some members of a household split their time between two or even more “homes” (e.g., university students and boarding school pupils live on campus during term time and go back to their parents’ house during term breaks), some people living in the same neighborhood may share a broadband router where the “home” network covers multiple households (which we could call an “extended home
network”), and students sharing a multi-room house may see it as a “pseudo-home.” Note that there can also be a hierarchical or graph-based structure among multiple home users, possibly device dependent (e.g., a primary user of a home device is a secondary user of another home device). Research on the privacy and security issues in a multi-user home is steadily growing [28, 63, 82, 113, 117, 118, 197, 200]. However, most studies in this area are focused on access control issues and power-play relationships between primary and secondary home users, overlooking the issues of an increasingly hybrid and extended home occupants [201]. Research on many aspects of multiple users in a single home, e.g., insider attacks and home users’ perception, security and privacy aspects of an “extended home network,” and a “pseudo-home” network, is missing from the current research literature.

5.3 Multiple Contexts and Contextual Factors/Parameters

Our SLR results showed evidence of research mainly in location- [120, 129] or device-based contexts [122, 173]. Although home itself may be considered a specific context, home users actually use the home network and home devices in the home for many different purposes, leading to multiple different (sub-)contexts of home networking where security and privacy aspects have to be studied differently. For instance, when using traditional computing devices (personal computers) and “smarter” home devices, the context of use is very different. Similarly, when working from home, there is a mixture and overlap between the work and home contexts. Furthermore, when a user brings home devices (e.g., mobile devices and wearables) outside of the home for controlling home devices remotely, an “extended home” context is created. More generally, each unique home networking scenario and each specific type of home device could define a unique context, and the different subsets of home devices that work together for a specific purpose also define different contexts. In addition to contexts defined by different usage scenarios and user intention/purposes, some contexts are more overarching and should be considered part of other contexts, e.g., the legal context regarding data protection matters about home devices that collect personal data. Context-aware security and privacy is a significant research area, and some past studies [157] have shown that concepts such as contextual histories dealing with the present and past contexts of the user can be used to enhance the competency and predict future contexts [50] adapt to user behaviors. However, as our SLR showed, research on different contexts and contextual factors/parameters is still relatively limited, and future work should venture into less studied contexts.

5.4 Data Flows across Multiple Devices and Multiple Users and in Multiple Contexts

Given the existence of multiple devices, multiple users, and multiple contexts in a typical home network and the complicated relationships between them, there can be complicated unidirectional and bidirectional data flows of different kinds, e.g., device-to-device, user-to-user, device-to-user, device-to-Internet, and user-to-Internet (the last two are about data flows between the home and the external world, mainly external online services and cloud servers on the Internet). These data flows might also differ in different contexts. Therefore, understanding such data flows is of particular importance for analyzing security and privacy issues and for developing more effective solutions. Researchers have been working around this topic [38, 91, 155], with a good deal of work focusing on device-to-Internet phenomena [20, 173], but a more systematic endeavor is still lacking. Hence, more comprehensive research is needed to consider the complexities of data flows inside a home and from/to the external world. These might consider different types of data flows between different entities in different contexts, how they lead to security and/or privacy threats and risks, how home users perceive such data flows, how home users respond to any security or privacy concerns, and how technical or socio-technical solutions can be developed.
based on knowledge of such data flows. In addition, more experimental work is required to test “hidden” data flows that are not explicitly specified in user manuals of home devices and privacy policies of the manufacturers.

5.5 Demographic Factors
Not surprisingly, our SLR revealed that gender and age are the two most-studied demographic factors in the literature. Some researchers also looked at effects of other demographic factors such as ethnicity, knowledge, education level, income level, and disability, though with a limited depth. Furthermore, as mentioned in Section 4.2.10, 39% of the studies were conducted in the UK, US, and Western Europe, suggesting a need for diversification of countries covered. Chen et al. [44] suggested that “geographical perspectives” could be instrumental in deciding human behaviors and hence it is important that further research should consider less studied areas. While some demographic factors have been less or not studied, even for more studied factor such as gender, we have observed conflicting results, so more research is needed to consolidate our understanding.

5.6 Home Users’ Awareness, Perceptions, Attitudes, Behaviors, and Practices
Although a lot of work has been done on these aspects, the research gaps we identified in the previous subsections suggest that there are still several gaps to be filled by further research. Many factors, including household types, types of home networks including those with multiple ge-locations [201], different user structures [118, 200], different usage contexts and scenarios, and different demographic factors, can affect home users’ awareness, perceptions, attitudes, behaviors, and practices. According to some past studies [27, 31, 73, 95], behavioral practices could be influenced by the level of awareness. Although different awareness enhancement initiatives are steadily increasing to help users understand the nuances of security and privacy at home, they are still not effective for non-expert users. Therefore, more research is needed to look into better ways and methods of increasing the privacy and security awareness of the users. Furthermore, a number of studies [87, 179] looked into issues of device configurations by users. These could be further investigated to address different issues, including weak authentication [177] and multi-user authorization (automatic configuration) [26]. Different ML algorithms including supervised classifiers [22, 134] and unsupervised learning algorithms such as LDA [22] have been used in past studies to both predict and analyze user behavior. However, further attention in this area is needed, especially in the context of multi-user and multi-device home to automatically learn and predict multi-user behaviors and issues in a connected landscape. In addition to more studies on less studied areas, some more holistic approaches are clearly needed, e.g., new taxonomies and ontologies that can cover different types of user perspectives and influencing factors.

5.7 Theoretical and Conceptual Frameworks
Our SLR has shown that past studies have considered the use and development of theoretical and conceptual frameworks, but mostly focusing on behavioral frameworks (e.g., PMT and TPB). On a more technical front, many taxonomies and ontologies have also been proposed [19, 78, 160, 168], but they mostly have a limited scope and do not cover user perspectives sufficiently or not at all. More precisely, there is much less work developing theoretical and conceptual frameworks connecting home computing, IoT and smart home, user perspectives, security and privacy aspects, and other important factors. We argue that a more advanced ontology needs developing to have a more holistic and comprehensive view of security and privacy of home networks, covering a wide range of aspects including at least the following: traditional computing devices (including personal computers, routers, and switches), smarter devices (including mobile devices, wearables, and IoT devices), physical and virtual network topologies, relevant software tools and
online services (including firmware in hardware devices, mobile apps, smart speaker skills, online management tools and services, etc.), household and user structures, demographic factors, mappings between home devices and capabilities, different threats and defense mechanisms, and different aspects of user perspectives (including awareness, attitude, perception, purposes and intention, behavior, activities, and practices). Developing such a comprehensive ontology is not trivial and should be based on existing taxonomies and ontologies covering different areas.

6 CONCLUSION

The purpose of this study is to conduct a systematic review of published papers on user perspectives of security and privacy aspects of a home network environment. It is evident from the results that this is quite a popular area of research and the number of studies, especially toward the later part of the last decade, has increased significantly in number and in depth. Despite many research papers published, the focus of most past studies is on issues and concerns arising from using a specific type of smart device (i.e., smart speaker), their security and privacy practices and related decisions, and underlying factors such as user trust and access control issues. Few studies explored the issues of multiple types of connected devices inside a home network (including smart devices, traditional computing devices, multiple smart devices and gateway devices, etc.) or considered the fluid boundaries of a digital home. Additionally, some researchers also discussed multi-user-related security and privacy concerns and behaviors. Research also highlighted the role of location- and device-specific contexts and demographic factors, such as age and gender, in shaping users’ security and privacy behaviors. Furthermore, the study collated theoretical and conceptual frameworks explaining the reasoning behind such users’ behaviors and actions.

Our work revealed a number of important research gaps and calls for more research in a range of key research areas, particularly around more holistic approaches (such as more advanced conceptual frameworks, especially a more comprehensive home networking and smart home ontology) considering multiple and inter-connected heterogeneous home devices, co-existence of several types of home users and other stakeholders, various contexts, data flows between different entities and in different contexts, and more demographic factors. In other words, we call for more future research to study the multi-dimensional complexity around security and privacy aspects of home networks and user perspectives, in order to make future home networks and smart homes more secure and privacy-friendly and meet people’s needs better.

REFERENCES

[1] Noura Abdi, Kopo M. Ramokapane, and Jose M. Such. 2019. More than smart speakers: Security and privacy perceptions of smart home personal assistants. In Proceedings of Fifteenth Symposium on Usable Privacy and Security (SOUPS’19). USENIX, 451–466. https://www.usenix.org/conference/soups2019/presentation/abdi.

[2] Mohammad Ali Nassiri Abrishamchi, A. Hanan Abdullah, A. David Cheok, and Kevin S. Bielawski. 2017. Side channel attacks on smart home systems: A short overview. In Proceedings of 43rd Annual Conference of the IEEE Industrial Electronic Society (IECON’17). IEEE, 8144–8149. https://doi.org/10.1109/IECON.2017.8217429

[3] Desiree Abrokwa, Shruti Das, Omer Akgul, and Michelle L. Mazurek. 2021. Comparing security and privacy attitudes among U.S. users of different smartphone and smart-speaker platforms. In Proceedings of Symposium on Usable Privacy and Security (SOUPS’21). USENIX, 139–158. https://www.usenix.org/conference/soups2021/presentation/abrokwa.

[4] Imtiaz Ahmad, Rosta Farzan, Apu Kapadia, and Adam J. Lee. 2020. Tangible privacy: Towards user-centric sensor designs for bystander privacy. Proceedings of the ACM on Human-Computer Interaction 4, CSCW2, Article 116 (2020), 28 pages. https://doi.org/10.1145/3415187

[5] Nazilah Ahmad, Umı Asma’Mokhtar, Wan Fariza Paizi Fauzi, Zulaila Ali Othman, Yusri Hakim Yeop, and Siti Norul Huda Sheikh Abdullah. 2018. Cyber security situational awareness among parents. In Proceedings of Cyber Resilience Conference (CRC’18). IEEE, 3 pages. https://doi.org/10.1109/CR.2018.8626830

[6] Icek Ajzen. 2011. The theory of planned behaviour: Reactions and reflections. Psychology & Health 26, 9 (2011), 1113–1127. https://doi.org/10.1080/08870446.2011.613995

ACM Computing Surveys, Vol. 55, No. 9, Article 180. Publication date: January 2023.
A Survey of User Perspectives on Security and Privacy

[7] Abdulwahid Al Abdulwahid, Nathan Clarke, Ingo Stengel, Steven Furnell, and Christoph Reich. 2015. Security, privacy, and usability – A survey of users’ perceptions and attitudes. In Proceedings of TrustBus 2015. Springer, 153–168. https://doi.org/10.1007/978-3-319-21906-5_12

[8] Mahdi Nasrullah Al-Ameen, Al-Ameen Chauhan, M. A. Manazir Ahsan, and Huzeyle Kocabas. 2021. A look into user’s privacy perceptions and data practices of IoT devices. Information and Computer Security 29, 4 (2021), 573–588. https://doi.org/10.1080/00180843.2020.1837487

[9] Ainiqa Alam, Heather Molyneaux, and Elizabeth Stobert. 2021. Authentication management of home IoT devices. In Proceedings of HCI for Cybersecurity, Privacy and Trust (HCI-CPT’21). Springer, 3–21. https://doi.org/10.1007/978-3-030-77392-2_1

[10] Ifitikhar Alam, Shah Khusro, and Muhammad Naeem. 2017. A review of smart TV: Past, present, and future. In Proceedings of International Conference on Open System & Technologies (iCOST’17). IEEE, 35–41. https://doi.org/10.1109/ICOST.2017.8279002

[11] Salem Aljanah, Ning Zhang, and Siok Wah Tay. 2021. A survey on smart home authentication: Toward secure, multi-level and interaction-based identification. IEEE Access 9 (2021), 130914–130927. https://doi.org/10.1109/ACCESS.2021.3114152

[12] Zahrah A. Almusaylim and Noor Zaman. 2019. A review on smart home present state and challenges: Linked to context-awareness internet of things (IoT). Wireless Networks 25, 6 (2019), 3193–3204. https://doi.org/10.1007/s11276-018-1712-5

[13] Omar Almutairi and Khalid Almarhabi. 2021. Investigation of smart home security and privacy: Consumer perception in saudi arabia. International Journal of Advanced Computer Science and Applications 12, 4 (2021), 614–622. https://doi.org/10.14569/IJACSA.2021.0120477

[14] Fayez Aloaiiba, Nathan Clarke, and Steven Furnell. 2017. An analysis of home user security awareness education. In Proceedings of 12th International Conference on Open System & Technologies (iCOST’17). IEEE, 116–122. https://doi.org/10.23919/ICTIST.2017.8356359

[15] Abdulfajeed Alqhatani and Heather Lipford. 2018. Exploring parents’ security and privacy concerns and practices. In Proceedings Workshop on Usable Security (USEC’18). Internet Society, 6 pages. https://doi.org/10.14722/usec.2018.23019

[16] Omar Alrawi, Chaz Lever, Manos Antonakakis, and Fabian Monrose. 2019. SoC: Security evaluation of home-based IoT deployments. In Proceedings of IEEE Security & Privacy (S&P’19). IEEE, 1362–1380. https://doi.org/10.1109/SP.2019.00013

[17] Abdalkrim M. Alshnta, Mohd Faizal Abdollah, and Ahmed Al-Haiqi. 2018. SDN in the home: A survey of home context-awareness internet of things (IoT). Cogent Engineering 5, 1, Article 1469949 (2018). https://doi.org/10.1080/23311916.2018.1469949

[18] Catherine L. Anderson and Ritu Agarwal. 2010. Practicing safe computing: A multimedia empirical examination of home computer user security behavioral intentions. MIS Quarterly 34, 3 (2010), 613–643. https://doi.org/10.2307/25750694

[19] Malik Nadeem Anwar, Mohammad Nazir, and Khurram Mustafa. 2017. Security threats taxonomy: Smart-home perspective. In Proceedings of 3rd International Conference on Advances in Computing,Communication & Automation (ICACCA Fall’17). IEEE, 4 pages. https://doi.org/10.1109/ICACCAF.2017.8344666

[20] Noah Apthorpe, Yan Svartzitsbnaider, Arunesh Mathur, Dillon Reisman, and Nick Feamster. 2018. Discovering smart home Internet of Things privacy norms using contextual integrity. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 2, 2, Article 59 (2018), 23 pages. https://doi.org/10.1145/3214262

[21] Judit Bar-Ilan. 2018. Tale of three databases: The implication of coveragedemonstratedforasamplequery. Frontiers in Research Metrics and Analytics 3, Article 6 (2018), 9 pages. https://doi.org/10.3389/frma.2018.00006

[22] Natä M. Barbosa, Zhuohao Zhang, and Yang Wang. 2020. Do privacy and security matter to everyone? Quantifying and clustering user-centric considerations about smart home device adoption. In Proceedings of Sixteenth Symposium on Usable Privacy and Security (SOUPS’20). USENIX, 417–435. https://www.usenix.org/conference/soups20/presentation/barbosa.

[23] Jhonnatan J. Barriga A. and Sang Guin Yoo. 2018. Security over smart home automation systems: A survey. In Proceedings of MICRADS 2018. Springer, 87–96. https://doi.org/10.1007/978-3-319-78605-6_7

[24] Susanne Barth and Menno D. T. de Jong. 2017. The privacy paradox – investigating discrepancies between expressed privacy concerns and actual online behavior – A systematic literature review. Telematics and Informatics 34, 7 (2017), 1038–1058. https://doi.org/10.1016/j.tele.2017.04.013

[25] Jordi Mongay Batalla, Athanasios Vasilakos, and Mariusz Gajewski. 2017. Secure smart homes: Opportunities and challenges. Comput. Surveys 50, 5, Article 75 (2017), 32 pages. https://doi.org/10.1145/3122816

[26] Jochen Bauer, Michael Hechtel, Christoph Konrad, Martin Holzwarth, Hiliko Hoffmann, Thomas Feld, Sven Schneider, Ingo Zinnikus, Andreas Mayr, and Jörg Franke. 2020. ForeSight - An AI-driven smart living platform, approach to
add access control to openHAB. In *Proceedings of International Conference on Smart Homes and Health Telematics (ICOST’20)*. Springer, 432–440. https://doi.org/10.1007/978-3-030-51517-1_40

[27] Carlos Bermejo Fernandez, Petteri Nurmi, and Pan Hui. 2021. Seeing is believing?: Effects of visualization on smart device privacy perceptions. In *Proceedings of 29th ACM International Conference on Multimedia (MM’21)*. ACM, 4183–4192. https://doi.org/10.1145/3474085.3475552

[28] Julia Bernd, Ruba Abu-Salma, and Alisa Frik. 2020. Bystanders’ privacy: The perspectives of nannies on smart home surveillance. In *Proceedings of 10th USENIX Workshop on Free and Open Communications on the Internet (FOCI’20)*. USENIX, 14 pages. https://www.usenix.org/conference/foci20/presentation/bernd

[29] Julia Bernd, Alisa Frik, Maritza Johnson, and Nathan Malkin. 2019. Smart home bystanders: Further complexifying a complex context. In *Proceedings of CI Symposium 2019*. PrivaCI, 6 pages. https://privaci.info/symposium2/papers_and_slides/Sub_Bernd_et_al_Bystanders_CI_2019.pdf.

[30] Chao Bian, Bing Ye, Anna Hoonakker, and Alex Mihailidis. 2021. Attitudes and perspectives of older adults on technologies for assessing frailty in home settings: A focus group study. *BMCGeriatrics* 21, 1, Article 298 (2021), 13 pages. https://doi.org/10.1186/s12877-021-02252-4

[31] Reuben Binns, Jun Zhao, Max Van Kleek, Nigel Shadbolt, Ilaria Liccardi, and Daniel Weitnzer. 2017. My bank already gets this data: Exposure minimisation and company relationships in privacy decision-making. In *Proceedings of Human Factors in Computing Systems (CHI’17)*. ACM, 2403–2409. https://doi.org/10.1145/3027063.3053255

[32] David M. Blei, Andrew Y. Ng, and Michael I. Jordan. 2003. Latent Dirichlet allocation. *Journal of Machine Learning Research* 3 (2003), 993–1022. https://www.jmlr.org/papers/volume3/blei03a/blei03a.pdf

[33] Thomas Bolton, Tooska Dargahi, Sana Belguith, Mabrook S. Al-Rakhami, and Ali Hassan Sohdro. 2021. On the security and privacy challenges of virtual assistants. *Sensors* 21, 7, Article 2312 (2021), 19 pages. https://doi.org/10.3390/s21072312

[34] Mathieu Boussard, Dinh Thai Bui, Richard Douville, Pascal Justen, Nicolas Le Sauze, Pierre Peloso, Frederik Van deputte, and Vincent Verdot. 2018. Future spaces: Reinventing the home network for better security and automation in the IoT era. *Sensors* 18, 9, Article 2986 (2018), 30 pages. https://doi.org/10.3390/s18092986

[35] Marius Brezovan and Costin Badica. 2013. A review on vision surveillance techniques in smart home environments. In *Proceedings of CSCS 2013*. IEEE, 471–478. https://doi.org/10.1109/CSCS.2013.30

[36] Joseph Bugeja and Andreas Jacobsson. 2019. On the design of a privacy-centered data lifecycle for smart living spaces. In *Proceedings of Privacy and Identity 2019*. Springer, 126–141. https://doi.org/10.1007/978-3-030-42504-3_9

[37] Joseph Bugeja, Andreas Jacobsson, and Paul Davidsson. 2016. On privacy and security challenges in smart connected homes. In *Proceedings of European Intelligence and Security Informatics Conference (EISIC’16)*. IEEE, 172–175. https://doi.org/10.1109/EISIC.2016.044

[38] Joseph Bugeja, Andreas Jacobsson, and Paul Davidsson. 2018. An empirical analysis of smart connected home data. In *Proceedings of ICIST 2018*. Springer, 134–149. https://doi.org/10.1007/978-3-319-94370-1_10

[39] Joseph Bugeja, Andreas Jacobsson, and Paul Davidsson. 2020. Is your home becoming a spy? A data-centered analysis and classification of smart connected home systems. In *Proceedings of Internet of Things (IoT’20)*. ACM, 17, 8 pages. https://doi.org/10.1145/3410992.3411012

[40] Sara Cannizzaro, Rob Procter, Sinong Ma, and Carsten Maple. 2020. Trust in the smart home: Findings from a nationally representative survey in the UK. *PLoS ONE* 15, 5, Article e0231615 (2020), 30 pages. https://doi.org/10.1371/journal.pone.0231615

[41] Aditya Chakraborti, Aastha Jain, ioddartha Menon, and Krishna Samdani. 2019. A review of security challenges in home automation systems. In *Proceedings of IEEE International Conference on System, Computation, Automation and Networking (ICSCAN’19)*. IEEE, 6 pages. https://doi.org/10.1109/ICSCAN.2019.8878722

[42] George Chalhoub and Ivan Flechais. 2020. “Alexa, are you spying on me?” Exploring the effect of user experience on the security and privacy of smart speaker users. In *Proceedings of HCI for Cybersecurity, Privacy and Trust (HCII’20)*. Springer, 305–325. https://doi.org/10.1007/978-3-030-50309-3_21

[43] Bing Chen, Yaping Liu, Shuo Zhang, Jie Chen, and Zhiyu Han. 2021. A survey on smart home privacy dataprotectiontechnology. In *Proceedings of Sixth International Conference on Data Science in Cyberspace (DSC’21)*. IEEE, 583–590. https://doi.org/10.1109/DSC53577.2021.00092

[44] Hao Chen, Kaisheng Lai, Lingnan He, and Rongjun Yu. 2020. Where you are is who you are? The geographical account of psychological phenomena. *Frontiers in Psychology* 11 (2020), 536. https://doi.org/10.3389/fpsyg.2020.00536

[45] Chola Chhetri and Vivian Motti. 2020. Identifying vulnerabilities in security and privacy of smart home devices. In *Proceedings of NCS Research Track 2020*. Springer, 211–231. https://doi.org/10.1007/978-3-030-58703-1_13

[46] Chola Chhetri and Vivian Genaro Motti. 2019. Eliciting privacy concerns for smart home devices from a user centered perspective. In *Proceedings of iConference 2019*. Springer, 91–101. https://doi.org/10.1007/978-3-030-15742-5_8

[47] M. A. Choukou, Y. Sakamoto, and P. Irani. 2021. Attitude and perceptions of older and younger adults towards ambient technology for assisted living. *European Review for Medical and Pharmacological Sciences* 25, 10 (2021), 3709–3717. https://doi.org/10.26355/eurrev_202105_25938
A Survey of User Perspectives on Security and Privacy

[48] Camille Cobb, Sruti Bhagavatula, Kalil Anderson Garrett, Alison Hoffman, Varun Rao, and Lujo Bauer. 2021. "I would have to evaluate their objections": Privacy tensions between smart home device owners and incidental users. *Proceedings on Privacy Enhancing Technologies* 2021, 4 (2021), 54–75. https://doi.org/10.2478/popets-2021-0060

[49] Andy Crabtree, Peter Tolmie, and Will Knight. 2017. Repacking “privacy” for a networked world. *Computer Supported Cooperative Work (CSCW)* 26, 4–6 (2017), 453–488. https://doi.org/10.1007/s10606-017-9276-y

[50] João H. da Rosa, Jorge L. V. Barbosa, and Giovane D. Ribeiro. 2016. ORACON: An adaptive model for context prediction. *Expert Systems with Applications* 45 (2016), 56–70. https://doi.org/10.1016/j.eswa.2015.09.016

[51] Brittany D. Davis, Janelle C. Mason, and Mohd Anwar. 2020. Vulnerability studies and security postures of IoT devices: A smart home case study. *IEEE Internet of Things Journal* 7, 10 (2020), 10102–10110. https://doi.org/10.1109/JIOT.2020.2983983

[52] Joanna F. DeFranco and Mohamad Kassab. 2021. Smart home research themes: An analysis and taxonomy. *Procedia Computer Science* 185 (2021), 91–100. https://doi.org/10.1016/j.procs.2021.05.010

[53] Marc Dupuis and Mercy Ebenezer. 2018. Help wanted: Consumer privacy behavior and smart home Internet of Things (IoT) devices. In *Proceedings of 19th Annual SIG Conference on Information Technology Education (SIGITE’18)*. ACM, 117–122. https://doi.org/10.1145/3241815.3241869

[54] Jade S. Edu, Jose M. Such, and Guillermo Suarez-Tangil. 2020. Smart home personal assistants: A security and privacy review. *Comput. Surveys* 53, 6, Article 116 (2020), 36 pages. https://doi.org/10.1145/3412383

[55] Saman Fatima, Naila Aiman Aslam, Iqra Tariq, and Nouman Ali. 2020. Home security and automation based on Internet of Things: A comprehensive review. In *Proceedings of Emerging Technologies in the field of Science and Engineering (ETSE’20)*. IOP, Article 012011, 12 pages. https://doi.org/10.1088/1757-899X/899/1/012011

[56] Davide Ferraris, Daniel Bastos, Carmen Fernandez-Gago, and Fadi El-Moussa. 2020. A trust model for popular smart home devices. *International Journal of Information Security* 20, 4 (2020), 571–587. https://doi.org/10.1007/s10207-020-00519-2

[57] Alain Forget, Sarah Pearman, Jeremy Thomas, Alessandro Acquisti, Nicolas Christin, Lorrie Faith Cranor, Serge Egelman, Marjan Harbach, and Rahul Telang. 2016. Do or do not, there is no try: User engagement may not improve security outcomes. In *Proceedings of Twelfth Symposium on Usable Security & Privacy (SOUPS’16)*. USENIX, 97–111. https://www.usenix.org/conference/soups2016/technical-sessions/presentation/forget.

[58] Jan Freudenreich, Jake Weidman, and Jens Grossklags. 2020. Responding to KRACK: Wi-Fi security awareness in private households. In *Proceedings of Human Aspects of Security and Assurance (HAISA’20)*. Springer, 233–243. https://doi.org/10.1007/978-3-030-57404-8_18

[59] Nicholas R. J. Frick, Konstantin L. Wilms, Florian Brachten, Teresa Hetjens, Stefan Stieglitz, and Björn Ross. 2021. The perceived surveillance of conversations through smart devices. *Electronic Commerce Research and Applications* 47, Article 101046 (2021), 16 pages. https://doi.org/10.1016/j.elerap.2021.101046

[60] Nathaniel Fruchter and Ilaria Liccardi. 2018. Consumer attitudes towards privacy and security in home assistants. In *Human factors in Computing Systems (CHI’18)*. EAs, ACM, Article LBW050, 6 pages. https://doi.org/10.1145/3170427.3188448

[61] Marco Furini, Silvia Mirri, Manuela Montangero, and Catia Prandi. 2020. On the usage of smart speakers during the Covid-19 coronavirus lockdown. In *Proceedings of GoodTechs 2020*. ACM, 187–192. https://doi.org/10.1145/3411170.3411260

[62] Attlee M. Gamundani, Amelia Phillips, and Hippolyte N. Muyingi. 2018. An overview of potential authentication threats and attacks on Internet of Things (IoT): A focus on smart home applications. In *Proceedings of iThings/GreenCom/CPSCom/SmartData 2018*. IEEE, 50–57. https://doi.org/10.1109/Cybermatics_2018.2018.00043

[63] Christine Geeng and Franziska Roesner. 2019. Who’s in control? Interactions in multi-user smart homes. In *Proceedings of CHI 2019*. ACM, 13 pages. https://doi.org/10.1145/3290605.3300498

[64] Joey F. George, Rui Chen, and Lingyao Yuan. 2021. Intent to purchase IoT home security devices: Fear vs privacy. *PLoS ONE* 16, 9, Article e0257601 (2021), 14 pages. https://doi.org/10.1371/journal.pone.0257601

[65] Fereshteh Ghaljaie, Mahin Naderifar, and Hamideh Golli. 2017. Snowball sampling: A purposeful method of sampling in qualitative research. *Strides in Development of Medical Education* 14, 3, Article e67670 (2017), 4 pages. https://doi.org/10.5812/sdme.67670

[66] Taqiayah-Khadijah Ghazali and Nur-Haryani Zakaria. 2018. Security, comfort, healthcare, and energy saving: A review on biometric factors for smart home environment. *Journal of Computers* 29, 1 (2018), 20. http://www.csrocg.org.tw/journal/JOC29_1/JOC-2901-17.pdf.

[67] Marco Ghiglieri, Melanie Volkamer, and Karen Renaud. 2017. Exploring consumers’ attitudes of smart TV related privacy risks. In *Proceedings of HAS 2017*. Springer, 656–674. https://doi.org/10.1007/978-3-319-58460-7_45

[68] Charulata Ghosh and Matthew S. Eastin. 2020. Understanding users’ relationship with voice assistants and how it affects privacy concerns and information disclosure behavior. In *Proceedings of HCI for Cybersecurity, Privacy and Trust (HCI’20)*. Springer, 381–392. https://doi.org/10.1007/978-3-030-50309-3_25
[69] Munkhjargal Gochoo, Fady Almajjar, Tan-Hsu Tan, and Sumayya Khalid. 2021. Towards privacy-preserved aging in place: A systematic review. Sensors 21, 9, Article 3082 (2021), 27 pages. https://doi.org/10.3390/s21093082

[70] Jennifer Golbeck. 2017. User concerns with personal routers used as public Wi-Fi hotspots. In Proceedings of IEEE 8th Annual Ubiquitous Computing, Electronics and Mobile Communication Conference (UEMCON’17). IEEE, 571–576. https://doi.org/10.1109/UEMCON.2017.8249878

[71] Phil Grünewald and Theresa Reisch. 2020. The trust gap: Social perceptions of privacy data for energy services in the united kingdom. Energy Research & Social Science 68, Article 101534 (2020), 8 pages. https://doi.org/10.1016/j.erss.2020.101534

[72] Nadine Guhr, Oliver Werth, Philip Peter Hermann Blacha, and Michael H. Breitner. 2020. Privacy concerns in the smart home context. SN-Applied Sciences 2, 2, Article 247 (2020), 12 pages. https://doi.org/10.1007/s42452-020-2025-8

[73] T. Gundu and S. V. Flowerday. 2013. Ignorance to awareness: Towards an information security awareness process. SAIEE Africa Research Journal 104, 2 (2013), 69–79. https://doi.org/10.23919/SAIEE.2013.8531867

[74] Hemant Gupta and Mayank Singh. 2019. Cyber threat analysis of consumer devices. In Proceedings of Advances in Computing and Data Sciences (ICACDS’19). Springer, 32–45. https://doi.org/10.1007/978-981-13-9942-8_4

[75] Punit Gupta, Sumit Bharadwaj, and Vipin Kumar Sharma. 2019. A survey to bridging the gap between energy and security in IoT and home. In Proceedings of Fifth International Conference on Image Information Processing (ICIIP’19). IEEE, 379–384. https://doi.org/10.1109/ICIIP47207.2019.8985841

[76] Julie Haney, Yasemin Acar, and Susanne Furman. 2021. ‘It’s the company, the government, you, and I’: User perceptions of responsibility for smart home privacy and security. In Proceedings of USENIX Security 2021. USENIX, 411–428. https://www.usenix.org/conference/usenixsecurity21/presentation/haney.

[77] Weijia He, Maximilian Golla, Roshni Padhi, Jordan Ofek, Markus Dürmuth, Earlene Fernandes, and Blase Ur. 2018. Rethinking access control and authentication for the home Internet of Things (IoT). In Proceedings of USENIX Security 2018. USENIX, 255–272. https://www.usenix.org/conference/usenixsecurity18/presentation/he.

[78] Ryan Heartfield, George Loukas, Sanja Budimir, Anatolij Bezemskii, Johnny R. J. Fontaine, Avgoustinos Filippoulitis, and Etienne Roesch. 2018. A taxonomy of cyber-physical threats and impact in the smart home. Computers & Security 78 (2018), 398–428. https://doi.org/10.1016/j.cossec.2018.07.011

[79] Justin T. Ho, David Dearman, and Khai N. Truong. 2010. Improving users’ security choices on home wireless networks. In Proceedings of Sixth Symposium on Usable Privacy and Security (SOP’12). ACM, 12, 12 pages. https://doi.org/10.1145/1183710.11837126

[80] Adele E. Howe, Indraijit Ray, Mark Roberts, Malgorzata Urbanska, and Zinta Byrne. 2012. The psychology of security for the home computer user. In Proceedings of IEEE Security & Privacy (S&P’12). IEEE, 209–223. https://doi.org/10.1109/SP.2012.23

[81] Kathy Huang and Zhanwei Wu. 2019. Perception of smart home devices and privacy by chinese users. In Proceedings of HCII 2019. Springer, 476–481. https://doi.org/10.1007/978-3-030-23528-4_65

[82] Yue Huang, Borke Obada-Obieh, and Konstantin (Kosta) Beznosov. 2020. Amazon vs. my brother: How users of shared smart speakers perceive and cope with privacy risks. In Proceedings of Conference on Human Factors in Computing Systems (CHI’20). ACM, Article 402, 13 pages. https://doi.org/10.1145/3313831.3376529

[83] Hyesun Hwang, Jaebye Suk, Kee Ok Kim, and Jihyung Hong. 2018. How consumers perceive home IoT services for control, saving, and security. In Proceedings of Human Interface and the Management of Information. Information in Applications and Services (HIM’18). Springer, 575–588. https://doi.org/10.1007/978-3-319-92046-7_47

[84] William Jang, Adil Chhabra, and Aarathi Prasad. 2017. Enabling multi-user controls in smart home devices. In Proceedings of IoTS&P 2017. ACM, 49–54. https://doi.org/10.1109/SITSP17.2017.1044731

[85] Yousra Javed, Shashank Sethi, and Akshay Jadoun. 2019. Alexa’s voice recording behavior: A survey of user understanding and awareness. In Proceedings of 14th International Conference on Availability, Reliability and Security (ARES’19). ACM, Article 89, 10 pages. https://doi.org/10.1145/3313825.3340330

[86] Lei Jin, Xuelian Long, and James B. D. Joshi. 2012. Towards understanding residential privacy by analyzing users’ activities in foursquare. In Proceedings of ACM Workshop on Building analysis datasets and gathering experience returns for security (BADGERS’12). ACM, 25–32. https://doi.org/10.1145/2382416.2382428

[87] Kim J. Kaaz, Alex Hoffer, Mahsa Saeidi, Anita Sarma, and Rakesh B. Bobba. 2017. Understanding user perceptions of privacy, and configuration challenges in home automation. In Proceedings of IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC’17). IEEE, 297–301. https://doi.org/10.1109/VLHCC.2017.8103482

[88] Ruogu Kang, Laura Dabbish, Nathaniel Fruchter, and Sara Kiesler. 2015. “My data just goes everywhere”: User mental models of the internet and implications for privacy and security. In Proceedings of Eleventh Symposium On Usable Privacy and Security (SOUPS’20). USENIX, 39–52. https://www.usenix.org/conference/soups2015/proceedings/presentation/kang.

[89] Harsurinder Kaur, Husanbir Singh Pannu, and Avleen Kaur Malhi. 2019. A systematic review on imbalanced data challenges in machine learning: Applications and solutions. Comput. Surveys 52, 4, Article 79 (2019), 36 pages. https://doi.org/10.1145/3343440

ACM Computing Surveys, Vol. 55, No. 9, Article 180. Publication date: January 2023.
A Survey of User Perspectives on Security and Privacy

[90] Mehran Mozaffari Kermani, Meng Zhang, Anand Raghunathan, and Niraj K. Jha. 2013. Emerging frontiers in embedded security. In Proceedings of International Conference on VLSI Design and 2013 12th International Conference on Embedded Systems (VLSID’13). IEEE, 203–208. https://doi.org/10.1109/VLSID.2013.222

[91] Damla Kilic, Andy Crabtree, Glenn McGarry, and Murray Goulden. 2022. The cardboard box study: Understanding collaborative data management in the connected home. Personal and Ubiquitous Computing 26, 1 (2022), 155–176. https://doi.org/10.1007/s00779-021-01655-9

[92] Dongyeon Kim, Kyuhong Park, Yongjin Park, and Jae-Hyeon Ahn. 2019. Willingness to provide personal information: Perspective of privacy calculus in IoT services. Computers in Human Behavior 92 (2019), 273–281. https://doi.org/10.1016/j.chb.2018.11.022

[93] Euiyoung Kim, JungKyoong Yoon, Jieun Kwon, Tiffany Liaw, and Alice M. Agogino. 2019. From innocent Irene to parental Patrick: Framing user characteristics and personas to design for cybersecurity. In Proceedings of the Design Society: International Conference on Engineering Design (ICED’19). Cambridge University Press, 1773–1782. https://doi.org/10.1017/dsi.2019.183

[94] Jane E. Klobas, Tanya McGill, and Xuequn Wang. 2019. How perceived security risk affects intention to use smart home devices: A reasoned action explanation. Computers & Security 87, Article 101571 (2019), 13 pages. https://doi.org/10.1016/j.cose.2019.101571

[95] Kathrin Knutzen, Florian Weidner, and Wolfgang Broll. 2021. Exploring augmented reality privacy icons for smart home devices and their effect on users’ privacy awareness. In Proceedings of International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct’21). IEEE, 409–414. https://doi.org/10.1109/ISMAR-Adjunct54149.2021.00093

[96] Martin J. Kraemer and Ivan Flechais. 2018. Researching privacy in smart homes: A roadmap of future directions and research methods. In Proceedings of Living in the Internet of Things 2018. IET, 10 pages. https://doi.org/10.1049/cp.2018.0038

[97] Elmarie Kritzinger and Sebastiaan H. van Solms. 2010. Cyber security for home users: A new way of protection through awareness enforcement. Computers & Security 29, 8 (2010), 840–847. https://doi.org/10.1016/j.cose.2010.08.001

[98] Oksana Kulyk, Kristina Milanovic, and Jeremy Pitt. 2020. Does my smart device provider care about my privacy? Investigating trust factors and user attitudes in IoT systems. In Proceedings of 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society (NordiCHI’20). ACM, Article 29, 12 pages. https://doi.org/10.1145/3419249.3420108

[99] Meral Korkmaz Kuyucu, Şerif Bahtiyar, and Gökhan İnce. 2019. Security and privacy in the smart home: A survey of issues and mitigation strategies. In Proceedings of 4th International Conference on Computer Science and Engineering (UBMK’19). IEEE, 113–118. https://doi.org/10.1109/UBMK.2019.8907037

[100] Evan Lafontaine, Afaq Sabir, and Anupam Das. 2021. Understanding people’s attitude and concerns towards adopting IoT devices. In Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems (CHI 2021 CHI EA). Article 307, 10 pages. https://doi.org/10.1145/3411763.3415633

[101] Federica Laricchia. 2022. Average number of devices residents have access to in households worldwide in 2020, by country. https://www.statista.com/statistics/1107307/average-number-connected-devices-households-worldwide/

[102] Jeremiah Lasquety-Reyes. 2021. Number of Smart Homes forecast for the segment Smart Appliances in the United Kingdom from 2017 to 2025 (in millions). https://www.statista.com/forecasts/887605/number-of-smart-homes-in-the-smart-home-segment-smart-appliances-in-the-united-kingdom/

[103] Josephine Lau, Benjamin Zimmerman, and Florian Schaub. 2018. Alexa, are you listening?: Privacy perceptions, concerns and privacy-seeking behaviors with smart speakers. Proceedings of the ACM on Human-Computer Interaction 2, CSCW, Article 102 (2018), 31 pages. https://doi.org/10.1145/3274371

[104] Hwansoo Lee. 2020. Home IoT resistance: Extended privacy and vulnerability perspective. Telematics and Informatics 49, Article 101377 (2020), 12 pages. https://doi.org/10.1016/j.tele.2020.101377

[105] Housub Lee and Alfred Kobsa. 2016. Understanding user privacy in Internet of Things environments. In Proceedings of WF-IoT 2016. IEEE, 407–412. https://doi.org/10.1109/WF-IoT.2016.7845392

[106] Jinyang Li, Zhenyu Li, Gareth Tyson, and Gaogang Xie. 2020. Your privilege gives you your privacy away: An analysis of a home security camera service. In Proceedings of IEEE Conference on Computer Communications (INFOCOM’20). IEEE, 387–396. https://doi.org/10.1109/INFOCOM441043.2020.9155516

[107] Wenda Li, Tan Yigitcanlar, Isil Erol, and Aaron Liu. 2021. Motivations, barriers and risks of smart home adoption: From systematic literature review to conceptual framework. Energy Research & Social Science 80, Article 102211 (2021), 29 pages. https://doi.org/10.1016/j.erss.2021.102211

[108] Huigang Liang and Xue Yajiong (Lucky). 2010. Understanding security behaviors in personal computer usage: A threat avoidance perspective. Journal of the Association for Information Systems 11, 7, 394–413. https://doi.org/10.17705/1jais.00232
[109] Bin Liao, Yasir Ali, Shan Nazir, Long He, and Habib Ullah Khan. 2020. Security analysis of IoT devices by using mobile computing: A systematic literature review. *IEEE Access* 8 (2020), 120331–120350. https://doi.org/10.1109/ACCESS.2020.3006358

[110] Yuting Liao, Jessica Vitak, Priya Kumar, Michael Zimmer, and Katherine Kritikos. 2019. Understanding the role of privacy and trust in intelligent personal assistant adoption. In *Proceedings of iConference 2019*. Springer, 102–113. https://doi.org/10.1007/978-3-030-15742-5_9

[111] Mar Lopez, Juana Pedraza, Javier Carbo, and Jose M. Molina. 2014. Ambient intelligence: Applications and privacy policies. In *Proceedings of Highlights of Practical Applications of Heterogeneous Multi-Agent Systems*. The PAAMS Collection (PAAMS’14). Springer, 191–201. https://doi.org/10.1007/978-3-319-07767-3_18

[112] Christoph Lutz and Gemma Newlands. 2021. Privacy and smart speakers: A multi-dimensional approach. *Information Society* 37, 3 (2021), 147–162. https://doi.org/10.1080/01972243.2021.1897914

[113] Nathan Malkin, Joe Deatrick, Allen Tong, Primal Wijesekera, Serge Egelman, and David Wagner. 2019. Privacy attitudes of smart speaker users. *Proceedings on Privacy Enhancing Technologies*. 4 (2019), 250–271. https://doi.org/10.2478/popets-2019-0068

[114] Lydia Manikonda, Aditya Deotale, and Subbarao Kambhampati. 2018. What’s up with privacy? User preferences and privacy concerns in intelligent personal assistants. In *Proceedings of Conference on AI, Ethics, and Society (AIES’18)*. ACM, 229–235. https://doi.org/10.1145/3278721.3278773

[115] Stefan Marksteiner, Victor Juan Exposito Jimenez, Heribert Valiant, and Herwig Zeiner. 2017. An overview of wireless IoT protocol security in the smart home domain. In *Proceedings of Internet of Things Business Models, Users, and Networks 2017*. IEEE, 8 pages. https://doi.org/10.1109/CTTE.2017.8260940

[116] Karola Marky, Sarah Prange, Florian Krell, Max Mühlhäuser, and Florian Alt. 2020. “You just can’t know about everything”: Privacy perceptions of smart home visitors. In *Proceedings of 19th International Conference on Mobile and Ubiquitous Multimedia (MUM’20)*. ACM, 83–95. https://doi.org/10.1145/3428361.3428464

[117] Karola Marky, Sarah Prange, Max Mühlhäuser, and Florian Alt. 2021. Roles matter! Understanding differences in the privacy mental models of smart home visitors and residents. In *Proceedings of 19th International Conference on Mobile and Ubiquitous Multimedia (MUM’21)*. ACM, 108–122. https://doi.org/10.1145/3490632.3490664

[118] Karola Marky, Alexandra Voit, Alina Stöver, Kai Kunze, Svenja Schröder, and Max Mühlhäuser. 2020. “I don’t know how to protect myself”: Understanding privacy perceptions resulting from the presence of bystanders in smart environments. In *Proceedings of 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society (NordiCHI’20)*. ACM, Article 4, 11 pages. https://doi.org/10.1145/3419249.3420164

[119] Karola Marky, Verena Zimmermann, Alina Stöver, Philipp Hoffmann, Kai Kunze, and Max Mühlhäuser. 2020. All in one! User perceptions on centralized IoT privacy settings. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI 2020 EAs)*. ACM, Article LBW071, 8 pages. https://doi.org/10.1145/3334480.3383016

[120] Faith McCreary, Alexandra Zafiropulu, and Heather Patterson. 2016. The contextual complexity of privacy in smart homes and smart buildings. In *Proceedings of HCI in Business, Government, and Organizations: Information Systems (HCIBGO’16)*. Springer, 67–78. https://doi.org/10.1007/978-3-319-39399-5_7

[121] Christopher D. McDermott, John P. Isaacs, and Andrei V. Petrovski. 2019. Evaluating awareness and perception of botnet activity within consumer Internet-of-Things (IoT) networks. *Informatics* 6, Article 8 (2019), 15 pages. https://doi.org/10.3390/informatics6010008

[122] Tanya McGill and Nik Thompson. 2017. Old risks, new challenges: Exploring differences in security between home computer and mobile device use. *Behaviour & Information Technology* 36, 11 (2017), 1111–1124. https://doi.org/10.1080/0144929X.2017.1352028

[123] Tanya McGill and Nik Thompson. 2018. Gender differences in information security perceptions and behaviour. In *Proceedings of Australasian Conference on Information Systems (ACIS’18)*. University of Technology Sydney ePress, 11 pages. https://doi.org/10.5130/acs2018.co

[124] Oliver Michler, Reinhold Decker, and Christian Stummer. 2019. To trust or not to trust smart consumer products: A literature review of trust-building factors. *Management Review Quarterly* 70 (2019), 391–420. https://doi.org/10.1007/s11301-019-00171-4

[125] Tomas Mikolov, Edouard Grave, Piotr Bojanowski, Christian Puhrsch, and Armand Joulin. 2017. Advances in Pre-Training Distributed Word Representations. arXiv:1712.09405 [cs.CL]. https://doi.org/10.48550/arXiv.1712.09405

[126] Annette Mills and Natasha Sahi. 2019. An empirical study of home user intentions towards computer security. In *Proceedings of 32nd Hawaii International Conference on System Sciences (HICSS’19)*. University of Hawai’i at Manoa, 4834–4840. https://doi.org/10.24251/HICSS.2019.583

[127] Ziarmal Nazar Mohammad, Fadi Farha, Adnan O. M. Abuassba, Shunkun Yang, and Fang Zhou. 2021. Access control and authorization in smart homes: A survey. *Tsinghua Science and Technology* 26, 6 (2021), 906–917. https://doi.org/10.26599/TST.2021.9010001
[128] David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G. Altman, and The PRISMA Group. 2009. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine* 6, 7, Article e1000097 (2009), 6 pages. https://doi.org/10.1371/journal.pmed.1000097 (website: http://www.prisma-statement.org/).

[129] Maria D. Molina, Andrew Gambino, and S. Shyam Sundar. 2019. Online privacy in public places: How do location, terms and conditions and VPN influence disclosure? In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI 2019 EAs)*. ACM, Article LBW2616, 6 pages. https://doi.org/10.1145/3290607.3312932

[130] Anouk Mols, Yijing Wang, and Jason Pridmore. 2021. Household intelligent personal assistants in the Netherlands: Exploring privacy concerns around surveillance, security, and platforms. *Convergence* 27, 6 (2021), 20 pages. https://doi.org/10.1177/1354856521942234

[131] Md. Moniruzzaman, Seyednima Khezr, Abdusalam Yassine, and Rachid Benlamri. 2020. Blockchain for smart homes: Review of current trends and research challenges. *Computers & Electrical Engineering* 103, Article 106585 (2020), 16 pages. https://doi.org/10.1016/j.compeleceng.2020.106585

[132] Zachary Munn, Micah D. J. Peters, Cindy Stern, Catalin Tufanaru, Alexa McArthur, and Edoardo Aromataris. 2018. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology* 18, 1, Article 143 (2018), 7 pages. https://doi.org/10.1186/s12874-018-0611-x

[133] Ajay Nadargi and Mythili Thirugnanam. 2019. Novel and efficient authentication scheme for IoE in smart home environment. *International Journal of Innovative Technology and Exploring Engineering* 27, 6, Article e1000097 (2019), 6 pages.

[134] Pardis Emami Naeini, Sruti Bhagavatula, Hana Habib, Martin Degeling, Lujo Bauer, Lorrie Faith Cranor, and Norman Sadeh. 2017. Privacy expectations and preferences in an IoT world. In *Proceedings of Thirteenth Symposium on Usable Privacy and Security (SOUPS’17)*. USENIX, 399–412. https://www.usenix.org/conference/soups2017/technical-sessions/presentation/naeini.

[135] Marcus Nohlberg and Joakim Kävrestad. 2020. Exploring information security and domestic equality. In *Proceedings of Human Aspects of Information Security and Assurance (HAISA’20)*. Springer, 224–232. https://doi.org/10.1007/978-3-030-57404-8_17

[136] Norbert Nthala and Ivan Flechais. 2017. “If it’s urgent or it is stopping me from doing something, then I might just go straight at it”: A study into home data security decisions. In *Proceedings of Human Aspects of Information Security, Privacy and Trust (HAS’17)*. Springer, 123–142. https://doi.org/10.1007/978-3-319-58460-7_9

[137] Norbert Nthala and Ivan Flechais. 2018. Informal support networks: An investigation into home data security practices. In *Proceedings of Fourteenth Symposium on Usable Privacy and Security (SOUPS’18)*. USENIX, 63–82. https://www.usenix.org/conference/soups2018/technical-sessions/presentation/nthala.

[138] Nobert Nthala and Ivan Flechais. 2018. Rethinking home network security. In *Proceedings of 3rd European Workshop on Usable Security (EuroUSEC’18)*. Internet Society, 11 pages. https://doi.org/10.14722/eurosec.2018.23011

[139] Antti Oulasvirta, Aurora Pihlajamaa, Jukka Perkiö, Debarshi Ray, Taneli Vihikangas, Tero Hasu, Niklas Vainio, and Petri Myllymäki. 2012. Long-term effects of ubiquitous surveillance in the home. In *Proceedings of ACM Conference on Ubiquitous Computing (UbiComp’12)*. ACM, 41–50. https://doi.org/10.1145/2370216.2370224

[140] Matthew J. Page, David Moher, Patrick M. Bossuyt, Isabelle Boutron, Tammy C. Hoffmann, Cynthia D. Mulrow, Larissa Shamseer, Jennifer M. Tetzlaff, Elie A. Akli, Sue E. Brennan, Roger Chou, Julie Glanville, Jeremy M. Grimshaw, Ashjarn Hrøbjartsson, Manoj M. Lalu, Tianjing Li, Elizabeth W. Loder, Evan Mayo-Wilson, Steve McDonald, Luke A. McGuinness, Lesley A. Stewart, James Thomas, Andrea C. Tricco, Vivian A. Welch, Penny Whiting, and Joanne E. McKenzie. 2021. PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ* 372, Article n160 (2021), 36 pages. https://doi.org/10.1136/bmj.n160

[141] Debajyoti Pal, Borworn Papasratorn, Wichian Chutimaskul, and Suree Funilkul. 2019. Embracing the smart-home revolution in asia by the elderly: An end-user negative perception modeling. *IEEE Access* 7 (2019), 38535–38549. https://doi.org/10.1109/ACCESS.2019.2906346

[142] Debajyoti Pal, Tuul Triyason, and Suree Funilkul. 2017. Smart homes and quality of life for the elderly: A systematic review. In *Proceedings of IEEE International Symposium on Multimedia (ISM’17)*. IEEE, 413–419. https://doi.org/10.1109/ISM.2017.83

[143] Debajyoti Pal, Xiangmin Zhang, and Saeed Siyal. 2021. Prohibitive factors to the acceptance of Internet of Things (IoT) technology in society: A smart-home context using a resistive modelling approach. *Technology in Society* 66, Article 101683 (2021), 16 pages. https://doi.org/10.1016/j.techsoc.2021.101683

[144] Jonghwa Park, Hanbyul Choi, and Yoonhyuk Jung. 2021. Users’ cognitive and affective response to the risk to privacy from a smart speaker. *International Journal of Human–Computer Interaction* 37, 8 (2021), 759–771. https://doi.org/10.1080/10447318.2020.1841422

[145] Sunjeong Park and Youn-kyung Lim. 2020. Investigating user expectations on the roles of family-shared AI speakers. In *Proceedings of ACM CHI Conference on Human Factors in Computing Systems (CHI’20)*. ACM, Article 323, 15 pages. https://doi.org/10.1145/3313831.3376450

ACM Computing Surveys, Vol. 55, No. 9, Article 180. Publication date: January 2023.
A Survey of User Perspectives on Security and Privacy

[166] Amit Kumar Sikder, Leonardo Babun, Z. Berkay Celik, Abbas Acar, Hidayet Aksu, Patrick McDaniel, Engin Kirda, and A. Selcuk Uluagac. 2020. Kratos: Multi-user multi-device-aware access control system for the smart home. In Proceedings of the 13th ACM Conference on Security and Privacy in Wireless and Mobile Networks (WiSec’20). ACM, 12 pages. https://doi.org/10.1145/3395351.3399358

[167] Deepika Singh, Ismini Psychoulia, Johannes Kropf, Sten Hanke, and Andreas Holzinger. 2018. Users’ perceptions and attitudes towards smart home technologies. In Proceedings of Smart Homes and Health Telematics, Designing a Better Future: Urban Assisted Living (ICOST’18). Springer, 203–214. https://doi.org/10.1007/978-3-319-94523-1_18

[168] Daniel J. Solove. 2006. A taxonomy of privacy. University of Pennsylvania Law Review 154, 3 (2006), 477–564. https://doi.org/10.2307/40041279

[169] Statista. 2021. Smart Home Report 2021 - Smart Appliances. https://www.statista.com/study/50587/smart-home-report-smart-appliances/.

[170] Jack Sturgess, Jason R. C. Nurse, and Jun Zhao. 2018. A capability-oriented approach to assessing privacy risk in smart home ecosystems. In Living in the Internet of Things: Cybersecurity of the IoT-2018. IET, 8 pages. https://doi.org/10.1049/cp.2018.0037

[171] Kaiwen Sun, Yixin Zou, Jenny Radesky, Christopher Brooks, and Florian Schaub. 2021. Child safety in the smart home: Parents’ perceptions, needs, and mitigation strategies. Proceedings of the ACM on Human-Computer Interaction 5, CSCW2, Article 471 (2021), 41 pages. https://doi.org/10.1145/3479858

[172] Yi Sun and Shihui Li. 2021. A systematic review of the research framework and evolution of smart homes based on the Internet of Things. Telecommunication Systems 77, 3 (2021), 597–623. https://doi.org/10.1007/s11235-021-00787-w

[173] Madhi Tabassum, Tomasz Kosinski, and Heather Richter Lipford. 2019. “I don’t own the data”: End user perceptions of smart home device data practices and risks. In Proceedings of Fifteenth Symposium on Usable Privacy and Security (SOUPS’19). USENIX, 435–450. https://www.usenix.org/conference/sousp2019/presentation/tabassum.

[174] Basma Taieb and Jean-Éric Pelet. 2019. The user’s attitude and security of personal information depending on the category of IoT. In Proceedings of New Knowledge in Information Systems and Technologies (WorldCIST’19), Vol. 931. Springer, 431–437. https://doi.org/10.1007/978-3-030-16184-2_41

[175] Mohammed Talal, A. A. Zaidan, B. B. Zaidan, A. S. Albahri, A. H. Alamoodi, O. S. Albahri, M. A. Alsalem, C. K. Lim, K. L. Tan, W. L. Shir, and K. I. Mohammed. 2019. Smart home-based IoT for real-time and secure remote health monitoring of triage and priority system using body sensors: Multi-driven systematic review. Journal of Medical Systems 43, 3, Article 42 (2019), 34 pages. https://doi.org/10.1007/s10916-019-1158-z

[176] Shuhaili Talib, Nathan L. Clarke, and Steven M. Furnell. 2010. An analysis of information security awareness within home and work environments. In Proceedings of International Conference on Availability, Reliability and Security (ARES’10). IEEE, 196–203. https://doi.org/10.1109/ARES.2010.27

[177] Liang Tan, Keping Yu, Fangpeng Ming, Xiaofan Cheng, and Gautam Srivastava. 2021. Secure and resilient artificial intelligence of things: A honeynet approach for threat detection and situational awareness. IEEE Consumer Electronics Magazine 11, 3 (2021), 69–78. https://doi.org/10.1109/MCE.2021.3081874

[178] Nik Thompson, Tanya Jane McGill, and Xuequn Wang. 2017. “Security begins at home”: Determinants of home computer and mobile device security behavior. Computers & Security 70 (2017), 376–391. https://doi.org/10.1016/j.cose.2017.07.003

[179] Ioanna Topa and Maria Karyda. 2018. Usability characteristics of security and privacy tools: The user’s perspective. In Proceedings of ICT Systems Security and Privacy Protection (SEC’18). Springer, 231–244. https://doi.org/10.1007/978-3-319-99828-2_17

[180] Daphne Townsend, Frank Knoefel, and Rafik Goubran. 2011. Privacy versus autonomy: A tradeoff model for smart home monitoring technologies. In Proceedings of Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS’11). IEEE, 4749–4752. https://doi.org/10.1109/EMBS.2011.6091176

[181] Hsin-yi Sandy Tsai, Mengtian Jiang, Saleem Alhabash, Robert LaRose, Nora J. Rifon, and Shelia R. Cotten. 2016. Understanding on triangle safety behaviors. Computers & Security 59 (2016), 138–150. https://doi.org/10.1016/j.cose.2016.02.009

[182] Betsy Uchendu, Jason R. C. Nurse, Maria Bada, and Steven Furnell. 2021. Developing a cyber security culture: Current practices and future needs. Computers & Security 109, Article 102387 (2021), 23 pages. https://doi.org/10.1016/j.cose.2021.102387

[183] Julia van Heek, Simon Himmel, and Martina Ziefle. 2017. Privacy, data security, and the acceptance of AAL-systems – a user-specific perspective. In Proceedings of Human Aspects of IT for the Aged Population. Aging, Design and User Experience (ITAP’17). Springer, 38–56. https://doi.org/10.1007/978-3-319-58530-7_4

[184] Joel Varghese and Thaier Hayajneh. 2018. A framework to identify security and privacy issues of smart home devices. In Proceedings of 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMC’18). IEEE, 135–143. https://doi.org/10.1109/UEMC.2018.8796765

ACM Computing Surveys, Vol. 55, No. 9, Article 180. Publication date: January 2023.
[180] Williams Vasanth, Sebastian J. Terence, and Immaculate Jude. 2019. Survey on Internet of Things based smart home. In Proceedings of International Conference on Intelligent Sustainable Systems (ICISS’19). IEEE, 460–464. https://doi.org/10.1109/ISSI.2019.8908112

[181] Rick Wash and Emilee Rader. 2015. Too much knowledge? Security beliefs and protective behaviors among United States internet users. In Proceedings of Symposium On Usable Privacy and Security (SOUPS’15). USENIX, 309–325. https://usenix.org/conference/soups2015/proceedings/presentation.wash

[182] Garry White, Tahir Ekin, and Lucian Visinescu. 2017. Analysis of protective behavior and security incidents for home computers. Journal of Computer Information Systems 57, 4 (2017), 353–363. https://doi.org/10.1080/08874417.2016.1232991

[183] Chathurangi Ishara Wickramasinghe and Delphine Reinhardt. 2019. A survey-based exploration of users’ awareness and their willingness to protect their data with smart objects. In Privacy and Identity 2019. Springer, 427–446. https://doi.org/10.1007/978-3-030-42504-3_27

[184] Wiktoria Wilkowska and Martina Ziefle. 2012. Privacy and data security in e-health: Requirements from the user’s perspective. Health Informatics Journal 18, 3 (2012), 191–201. https://doi.org/10.1177/1460458212442933

[185] Wiktoria Wilkowska, Martina Ziefle, and Simon Himmel. 2015. Perceptions of personal privacy in smart home technologies: Do user assessments vary depending on the research method? In Proceedings of Human Aspects of Information Security, Privacy, and Trust (HAS’15). Springer, 592–603. https://doi.org/10.1007/978-3-319-20376-8_53

[186] Charlie Wilson, Tom Hargreaves, and Richard Hauxwell-Baldwin. 2015. Smart homes and their users: A systematic analysis and key challenges. Personal and Ubiquitous Computing 19, 2 (2015), 463–476. https://doi.org/10.1007/s00779-014-0813-0

[187] Peter Worthy, Ben Matthews, and Stephen Viller. 2016. Trust me: Doubts and concerns living with the Internet of Things. In Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS’16). ACM, 427–434. https://doi.org/10.1145/2901790.2901890

[188] Umesh Hodeghatta Rao Xavier and Bishwa Prakash Pati. 2012. Study of internet security threats among home users. In Proceedings of Fourth International Conference on Computational Aspects of Social Networks (CASoN’12). IEEE, 217–221. https://doi.org/10.1109/CASoN.2012.6412405

[189] Wenyan Yan, Zhihiao Wang, Hao Wang, Wendong Wang, Junhui Li, and Xiaolin Gui. 2020. Survey on recent smart gateways for smart home: Systems, technologies, and challenges. Transactions on Emerging Telecommunications Technologies, Article e4067 (2020), 20 pages. https://doi.org/10.1002/ett.4067

[190] Salifu Yusif, Jeffrey Soar, and Abdul Hafeez-Baig. 2016. Older people, assistive technologies, and the barriers to adoption: A systematic review. International Journal of Medical Informatics 94 (2016), 112–116. https://doi.org/10.1016/j.ijmedinf.2016.07.004

[191] Eric Zeng and Franziska Roesner. 2019. Understanding and improving security and privacy in multi-user smart homes: A design exploration and in-home user study. In Proceedings of USENIX Security 2019. USENIX, 159–176. https://www.usenix.org/conference/usenixsecurity19/presentation/zeng

Received 26 October 2021; revised 22 July 2022; accepted 2 August 2022

ACM Computing Surveys, Vol. 55, No. 9, Article 180. Publication date: January 2023.