Abstract—Massive progress of mobile wireless telecommunication networks was achieved in the previous decades, with privacy enhancement in each. At present, mobile users are getting familiar with the latest 5G networks, and the discussion for the next generation of Beyond 5G (B5G)/6G networks has already been initiated. It is expected that B5G/6G will push the existing network capabilities to the next level, with higher speeds, enhanced reliability, and seamless connectivity. To make these expectations a reality, research is progressing on new technologies, architectures, and intelligence-based decision-making processes related to B5G/6G. Privacy considerations are a crucial aspect that needs further attention in such developments, as billions of people and devices will be transmitting their data through the upcoming network. This paper provides a comprehensive survey on privacy-related aspects for B5G/6G networks. First, it discusses a taxonomy of different privacy perspectives. Based on the taxonomy, the paper then conceptualizes a set of privacy goals for the B5G/6G and the challenges that appear as barriers to reaching these goals. Next, this work provides a set of solutions applicable to the proposed architecture of B5G/6G networks to mitigate the challenges. Additionally, this paper discusses the emerging field of non-personal data privacy. It also provides an overview of standardization initiatives for privacy preservation. Finally, it concludes with a roadmap of future directions and upcoming trends containing privacy-related topics, which will be an arena for new research towards privacy-enhanced B5G/6G networks. This work provides a basis for privacy aspects that will significantly impact people’s daily lives with future networks.

Index Terms—Beyond 5G, 6G, privacy, personal and non-personal data, survey

I. INTRODUCTION

Wireless mobile communication networks perform the transmission of information through radio waves. The primary concern of these networks is to establish a connection between two parties, despite physical barriers and without using any medium. However, with the proliferation of wireless network connectivity, we observe tremendous improvements in the techniques that derive a seamless experience of smooth connectivity to daily activities. We can see that the wireless network generation named “1G” has evolved to the present “4G” within four decades. It gradually upgraded with increasing usability, applications, security, and privacy each decade. The roll-out of “5G” worldwide in this decade has already started, eventually becoming a part of our daily activities. We observe the time difference between two generations is also declining [1]. Therefore, this development continues to B5G/6G, which will promise even more speed capabilities and open new doors to a wide range of associated technologies.

The importance of B5G/6G lies in its impact on the lifestyle of the general public. According to the white paper from ITU [2], citizens and humans will be placed at the very centre of the next-generation internet by increasing the capabilities of network technology for all aspects of human interactions. It is expected that the 6G networks would be highly scalable with every domain of coverage [3]. Therefore, users will get a seamless range of high-speed connectivity of B5G/6G wherever they go. According to [2], the critical drivers for lifestyle and societal changes with futuristic networks in the 2030s would be:

- New types of communication modes: Technologies to reduce the overhead of being physically present, provide more interactive telepresence and collaborations, create a range of applications such as industry-based digital twin and medical imaging volumetric data.
- Multi-sense networks: Create a fully immersive experience involving multiple physical senses, including smell and taste.
- Time engineered applications: Experience ultra-smooth connectivity with better Quality of Service (QoS).
- Critical infrastructure: Providing users with secure, reliable connectivity despite the location barriers.

The limitations in current 5G networks are also a key driver for the progression to B5G/6G networks. For instance, the existing 5G networks have a latency of 1 ms, but this is too long for Industrial Internet-of-Things (IIoT) applications [4]. Therefore, B5G/6G networks will fill this gap by introducing high-speed, reliable connections for IIoT.

We can see that the upcoming changes focus on providing new mobility experiences with enhanced QoS anywhere. The network providers should develop the underlying technologies...
A. Why Privacy is Critical in B5G/6G

With the provision of enhanced features in B5G/6G, such as massive speeds in communication and ultra-high availability, it opens a gateway of many possibilities of having a wide range of facilities in daily life that ease people's daily tasks. The chance of achieving harmony among hundreds of devices connected around a person is already underway and will be a general reality through future networks. Since these devices are connected, communicate with nearby devices, and stream data continuously, it will digitally create a very sophisticated inter-connectivity that makes it virtually possible to track every user action. Therefore, B5G/6G networks will eventually lead the way to create a fully automated smart environment that may span over a vast population, such as smart cities.

Since this seems inevitable, it is clear that privacy requires extreme importance here. As the connectivity brings people together, it also drastically increases the possibility of identifying individuals, their health status, current actions, prediction of decisions, motion, interests, habits, personal beliefs, ideologies, etc. One may do this by analysing the data output through sensors, smartphones, and other personal electronic devices with network connectivity. As B5G/6G will facilitate their communication, these devices will not be isolated anymore. Therefore, third parties may accumulate a wide range of signals and extract this information on the data subjects/users. For example, a smart light connected wirelessly with a remote server or smart device can increase the house's energy efficiency. However, at the same time, it can collect data on when a user is at home, which rooms are used often, whether there are people in the house, which provide insights on user habits, preferences, and daily routine [5].

With the facilitation of capabilities by B5G/6G networks, new technology applications such as extended reality, smart medical systems, autonomous driving, etc., can be expected soon. Then, there will be many protocols, algorithms, and different device brands that will increase the complexity of the network. The work in [5] shows as B5G/6G networks will be having this increased network heterogeneity, there will be more concerns on privacy than the previous generations. For example, they show the involvement of connected devices in every aspect of humans, such as medical implants, which could pose serious concerns of potential leaks of personal information such as health records. Especially, this could happen if an adversary detects a privacy vulnerability in algorithms of such systems or transfer data through protocols that give lesser concern on data privacy.

B. Motivation

The advent of the study of the next generation of mobile networks has already begun in the research community as we see
a lot of related work in the B5G/6G. All of the surveys in [6]–[15] have a clear focus on B5G/6G networks. The work in [6] gives an overview of both privacy and security issues related to 6G networks. In [7], the authors have discussed Machine Learning (ML) privacy aspects, such as issues and protection related ML in 6G networks. Comprehensive discussions on the progression of mobile networks up to present 5G networks and beyond, their technologies, and challenges are discussed in multiple works including [8], [10]–[15]. The survey in [9] provides a vision and a set of Key Performance Indicators (KPI) for 6G networks. The work in [10] discusses potential privacy issues from technologies associated with 6G networks. The survey in [11] puts a special focus on the 6G requirements and trends, associated technologies, and challenges. Similarly, the work in [12]–[15] discuss the technologies associated with 6G networks and potential challenges. The authors in [11] also discuss standardization approaches for 6G networks. Table II provides a summary of these surveys.

We noticed the key highlight in all of these related surveys is the lack of investigation and discussion on 6G privacy-related aspects. The research on privacy for B5G/6G is still at an early stage [6]. There is a lack of privacy-specific surveys for the B5G/6G networks. We observe the existing ones do not intensely discuss aspects related to privacy but rather contain ideas ranging from how Artificial Intelligence (AI)/ML is used with B5G/6G [7], or addressing security-related issues mixed with privacy [6].

Also, we see there will be paramount importance to privacy in B5G/6G networks. With the capabilities of these networks, a lot of loopholes in privacy will be available as there will be a lot of emerging technologies that billions of people would use. The massive data rates provided by future networks will ease the data collection, real-time surveillance, and track sensory data. It will ultimately result in understanding feelings and emotions from the signals and behaviours of people who may use services from these technologies.

Therefore, we consider this work as a useful starting point to identify key privacy issues that would arise with the B5G/6G networks. In this work, we focus on the current issues of privacy of B5G/6G and potential solutions to these issues. Also, we see numerous future directions also available for the privacy of B5G/6G that could be used to mitigate the problems, enhance the solutions, or be used as a potential starting point to begin.

C. Our Contribution

To the best of our knowledge, this is the first attempt at comprehensively investigating privacy-related aspects of B5G/6G networks, within a broad range as indicated by Table II. The following key points highlight our contributions to this survey:

- **Identify privacy taxonomy**: Investigate different taxonomies for privacy defined by consideration of various aspects of privacy requirements.
- **Propose a set of privacy goals for B5G/6G**: These goals that should be fulfilled to ensure and enhance privacy for B5G/6G networks.
- **Explore potential privacy issues in B56/G6**: Based on the privacy goals, we identify possible privacy issues that could be affected when reaching them.
- **Discuss privacy solutions for the issues**: The potential solutions that could be used to address the mentioned issues are also identified.
- **Investigate non-personal data privacy**: This paper also investigates privacy aspects of non-personal data, which is a new area that has not been discussed in the previous work.
- **Discuss 6G privacy projects and standardization**: We summarize the existing privacy projects applicable for 6G and also the standardization efforts made to achieve privacy preservation and enhancement.
- **Summarize lessons learned and propose future directions for B5G/6G privacy**: The key messages from the research are discussed, and the future actions for them are presented, with the possible challenges to be addressed.

D. Outline

| Title: A Survey on Privacy for B5G/6G: New Privacy Goals, Challenges, and Research Directions |
| Why is this survey paper required? |
| Section II: Introduction |
| What is B5G? |
| Section III: Taxonomy and Privacy Goals |
| What are the taxonomy and goals of 6G privacy? |
| Section IV: 6G Privacy Challenges and issues |
| What are the challenges? |
| Section V: Privacy Solutions |
| What are the solutions? |
| Section VI: Privacy Projects and Standardisation |
| Is 6G privacy an important research for international peers? |
| Section VII: Lessons Learned and Future Research Directions |
| Why consider non-personal data for 6G privacy? |
| Section VII: Lessons Learned and Future Research Directions |
| What is more in the future? |
| Section IX: Emerging and Future Research Directions Related to 6G Privacy |
| Section X: Conclusion |

Fig. 1. Outline of the present study.

The rest of the paper is organized as follows. Section II outlines the details of the 6G network and its architecture. Section III discusses the privacy taxonomy with goals to be achieved. Issues that could arise when attempting to reach the goals are discussed in Section IV. The proposed solutions to address these issues are described in Section V. Section VI discusses on non-personal data for 6G privacy. The standardization and 6G privacy projects are summarized in Section VII whereas Section VIII provides insights on lessons learned and possible future directions. Further research directions on emerging topics are portrayed in Section IX. Finally, Section X concludes the paper. Figure 1 provides an outline of the Sections and the arrangement of the paper, and Table II provides a summary of all acronyms used in this study.
TABLE II
SUMMARY OF IMPORTANT SURVEYS ON 6G PRIVACY

| Ref. | 6G Network | Taxonomy and Privacy Goals | Privacy Challenges and Issues | Privacy solutions | Non-personal data 6G privacy | Future Privacy Research Directions | Remarks |
|------|-------------|---------------------------|-------------------------------|-------------------|-----------------------------|----------------------------------|---------|
| 6    | M           | M                         | M                             | M                 | L                           | M                                | Overview of vulnerabilities in legacy networks, required security and privacy enhancements for 6G, security and privacy issues, security and privacy solutions for 6G, technical challenges. |
| 7    | H           | M                         | L                             | H                 | M                           | H                                | Mobile network evolution to 6G, security and privacy issues, applications of ML in 6G, new trends and open issues in ML privacy. |
| 8    | H           | M                         | M                             | M                 | L                           | M                                | 6G security and privacy requirements, vision and KPIs, security and privacy challenges, discussion on privacy aspects for 6G. |
| 9    | M           | M                         | M                             | M                 | M                           | M                                | 6G networks technologies, potential security and privacy issues from the technologies. |
| 10   | H           | L                         | M                             | M                 | L                           | M                                | 6G requirements and trends, revolutionary technologies, 6G challenges and future research directions. |
| 11   | H           | L                         | M                             | M                 | L                           | L                                | 6G requirements and trends, revolutionary technologies, 6G challenges and future research directions. |
| 12   | H           | L                         | L                             | L                 | L                           | L                                | 5G NR features and use-cases, migration towards B5G/6G, 6G networks requirements, research challenges. |
| 13   | H           | L                         | L                             | L                 | L                           | L                                | Evolution of mobile networks, innovations and emerging technologies. |
| 14   | H           | L                         | L                             | L                 | L                           | L                                | Requirements and trends in 6G, KPIs and usecases, technologies for 6G, and challenges. |
| 15   | H           | L                         | M                             | L                 | M                           | L                                | Current developments of 6G, Limitations of existing 5G mobile networks, new technology enablers for 6G, standardization approaches |
| This paper | H | H | H | H | H | A comprehensive survey on B5G/6G networks, privacy taxonomy and goals, possible challenges and issues, potential solutions for the issues, non-personal data for 6G privacy, standardization approaches, and future research directions. |

II. 6G NETWORK

The progression of wireless networks has come a long way from several decades to the present. It has passed multiple “generations”, wherein each new generation sees significant progress in the previous generation’s coverage, reliability, speed, security, and privacy aspects.

A. Evolution of Mobile Networks

From the beginning of 1G in the 1980s to the current 5G era, privacy has played a key requirement in mobile communications and networking, with a new generation emerging each decade.

1) 1G: The First Generation: The 1G telecommunication networks were analog systems that used radio signals of frequency of 150 MHz, with only voice transmission [16]. It is the first commercialized operation of wireless networks where general consumers could experience mobile connectivity in voice communication. The radio communication traffic was multiplexed to Frequency Division Multiple Access (FDMA) [16], which is a technique to virtually dividing the bandwidth to different frequency ranges to facilitate parallel data transmission of multiple users. A drawback in first-generation telecommunication was the cost since it was based on monopoly operators who received the spectrum free-of-charge [17]. The costs of phone calls and subscriptions were very high due to lack of infrastructure [17].

Considering the privacy aspects in the first generation, we can find a lot of privacy issues such as unencrypted communications and no guarantees of security or privacy. It led to many problems such as cloning, eavesdropping, and illegal access [8]. However, the first portability experience of these 1G networks paved the way for considering these issues. It evolved into an enhanced version of 2G, which was more popular due to being more affordable, secure, and having better coverage.

2) 2G Global System for Mobile Communication (GSM): The 2G networks were first introduced in 1991, with digital signals that facilitated more clear voice calls, text, and multimedia messages via mobile phones [16]. The GSM was the most prominent representative of 2G networks, where GSM was based on Time Division Multiple Access (TDMA) [18]. It offered data rates up to 57.6 kbps via the aggregation of four radio channels with 14.4 kbps [18]. It also provided a low-volume data service to subscribers. Due to its increased popularity, General Packet Radio Service (GPRS) was introduced in 1997, an ‘update’ called 2.5 G for the 2G, offering
up to 172 kbps rate. Later, Enhanced Data Rates for GSM Evolution (EDGE) boosted the speed up to 230 kbps through a more efficient modulation scheme [18].

With the increased user attention on new features provided by 2G with digital communication, the mobile internet, and SMS/MMS, we see a significant privacy improvement in 2G networks, with digital modulation secured with encryption and temporary identifiers for anonymity. Yet it also had several security loopholes, as only one-way authentication of a user is allowed, where the user cannot authenticate the network [8].

3) 3G Universal Mobile Telecommunication System (UMTS): In 2000, the 3G UMTS was introduced, with a new radio technology of Wideband Code Division Multiple Access (WCDMA). It supported data rates up to 2 Mbps in stationary conditions and 384 kbps with moderate motion [18]. The 3rd Generation Partnership Project (3GPP) was founded in 1998 to define the standards and protocols and aid in the deployment of 3G networks. It has continued to progress with the work by defining a versatile framework. The 3GPP was initiated due to the need of fulfilling the performance requirements of the International Mobile Telecommunication-2000 standard [16]. The 3G networks are mainly focused on delivering increased bit rates to satisfy the expected demand from users on data-intensive services, such as video telephony and downloads [18]. The updates on speeds such as ’3.5G’ were released with 3GPP standardized High-Speed Downlink Packet Access (HSDPA), which increases downlink speeds to 7.2 Mbps. Later Evolved High-Speed Packet Access (HSPA+) was released, which has a theoretical throughput of 337 Mbps in downlink and 34 Mbps in the uplink [18].

The privacy issues in 2G were mitigated in 3G during the 2000s and provided enhanced speeds that practically enabled the internet through mobile and online streaming of data. However, 3G also came with several privacy issues, including caching of International Mobile Subscriber Identity (IMSI) and 3G/GSM-interoperability privacy leakages [19].

4) 4G Long Term Evolution (LTE): The Fourth Generation of mobile networks was introduced in 2011, with the LTE standard to fulfill the demands of mobile internet traffic. It is designed to support only packet-switched services, in contrast to the previous generations with circuit switching [18]. Therefore, the 4G networks are all-IP standard, which is one of the main turning points in 4G, compared with the previous generations. 4G further enhances the capability of high-quality video streaming and high speed. The latest downlink speed for 4G ranges up to 1.2 Gbps, referred to as “Gigabit LTE”. The uplink peak data rate could go up to 150 Mbps [18].

At present, 4G is widely used globally. These fast data rate experiences and applications such as High Definition (HD) video streaming have become an easy, day-to-day task. However, despite having these enhanced high data rates, 4G also consists of privacy vulnerabilities. They include fine-grained location leaks, heterogeneous wireless networks causing privacy issues with different data types, and incompatibilities in encryption of 3G networks with 4G [20]. [21].

B. 5G Networks

The latest addition to the mobile networks is the fifth generation, where the first release of this generation was in 2018 [18]. More mobile devices support 5G, and the telecommunication providers are rapidly increasing the 5G coverage over the populated areas. The key difference between 4G and 5G is the speed. Therefore, currently, it is rapidly undergoing commercialization, offering peak data rates of 20 Gbps for downlink and 10 Gbps for uplink, with user experienced data rates offering 100 Mbps downlink and 50 Mbps for uplink [12]. An entirely new radio air interface, known as the 5G New Radio or 5G NR air interface, has been designed to meet these requirements of the 5G network [12].

The previous 4G networks cannot deliver applications requiring high data rates such as Virtual Reality (VR), Augmented Reality (AR), HD screening, and 360° video streaming. It has now become possible with 5G as it has achieved the required data rates through the use of a wide range of technologies such as the ones listed in [12] and [22]:

- Massive Multiple-Input Multiple-Output (MIMO) - equip cellular base stations with a large number of antennas to provide uniformly good services to users in high mobility environments [23].
- Ultra-Dense Networks - Highly dense networks with a large number of communication links in a unit area.
- Full-duplex radio - Simultaneously send and receive signals over the same spectrum channel, to achieve nearly doubled channel capacity [24].
- Device-to-device communication - Communication directly among end devices, without transmission through an infrastructure node such as access points or base stations [25].
- Multi-Radio Access Technology (multi-RAT) - Capability of connecting to more than one cellular network type.
- Cognitive radio - The capability of the signal transceiver to intelligently identify the vacant communication channels and perform switching.
- Millimetre-wave transmission - Use of short wavelengths in the range of millimeters, in the frequency range of 30 GHz to 300 GHz [16], to achieve higher bandwidth in data transmission for a shorter distance.
- Network Function Virtualization (NFV) - Functions with hardware compatibility issues can be run on cloud computing infrastructure using virtualization of network functions, making reusable network infrastructure [26].
- Software Defined Networks (SDN) - Network management approach that facilitates programmability of the network by external applications [27].

However, there are various privacy concerns in 5G networks as well. The works in [28], [29] comprehensively discuss the existing issues in 5G privacy, which will additionally be applicable for upcoming networks beyond 5G. They include ambiguity in data ownership, loss of governance/control, IoT privacy, issues in trans-border information flows, use of third parties, and having different objectives for trust. Some of these issues are discussed in Section [5] as privacy issues for 5G/6G networks as well since the already existing 5G...
privacy issues will also be applicable for future networks as mentioned.

C. Transition from 5G to 6G

It is anticipated in 2030s that the society will be highly intelligence-inspired, digitalized, and globally data-driven, with near-instant full wireless connectivity [40]. To facilitate future changes in the next decade, a transition from 5G to B5G/6G will be necessary. 6G is expected to deliver data rates 100 to 1000 times faster than 5G with up to terabit-per-second speeds [4] to cope with the near-instant connectivity challenge. The work in [31] shows that 6G should consist of a drastically improved user-experienced data rate, which should also be 100 to 1000 times better when compared with 100 Mbps downlink user-experienced rate in 5G. Also, the control plane latency should be significantly lower in 6G, making applications that require rapid responsiveness possible when remotely operated, which is still a far-fetched idea with a latency of 10 ms in 5G. The features provided by B5G/6G will undoubtedly open gateways to a wide range of associated applications that do not exist today. Most of these can be anticipated to be connected with providing ultra-realistic beyond current sensory inputs such as visual or auditory [31] but extending to other sensations as well. Also, it could be assumed that billions of devices will be connected, providing much more capabilities by fully digitalizing the society and the underlying infrastructure, with use-cases such as smart cities. The coverage will allow providing universal public services, despite the location boundaries due to B5G/6G ubiquitous coverage [31].

The current 5G networks have characteristics of migrating applications to cloud, software driven networking, virtualization, and slicing, but 6G will have all these features with an extra layer of intelligence added [32]. We can expect a lot of automation by 2030, and the creation of distributed intelligence to support automation will be commonplace in these future networks [2]. The future generation networks will also come with many smart applications that use this decentralized, distributed intelligence. Their application scenarios could be categorized into three forms: 1) intelligent life and intelligent interaction, 2) intelligent production, which supports scenarios such as smart agriculture, intelligent industry-related applications, and 3) intelligent society that enjoys super transportation with fully self-navigation [31]. Therefore, the future networks will enhance the data transmission speeds via physical means or radio technologies and with intelligent management service provision, which is currently not available in the current networks.

Therefore, transition of B5G/6G networks from existing 5G can be considered as a combination of improvements that we see from previous generations, such as enhancements in data rates, lesser latencies, higher reliability, coverage. It will also come with a touch of intelligence to manage the complexity and cope with real-time decision-making requirements in high-speed environments. Moreover, the potential with these future networks will completely shift the conventional ideas in just achieving higher speeds in the next generation, but fully impacting how people interact with the world, their reality, sensations, and decision making.

D. 6G Architectures

To meet the expectations for B5G/6G, novel architectures are designed by adding AI as a key component. The work in [33] provides a layered architecture for B5G/6G considering AI-enabled functions. It includes four layers for 6G architecture which consists of:

- **Intelligent Sensing Layer** - Sense data from physical environments through AI-enabled devices or crowds of humans.
- **Data Mining and Analytics Layer** - Process and analyze raw data from a massive number of devices for knowledge discovery, with the aid of AI-based data mining approaches.
- **Intelligent Control Layer** - Learning, optimization and decision-making process for 6G network functionalities, with the prominent use of AI models that can adapt and automatically make decisions by itself.
- **Smart Application Layer** - Deliver application-specific functionalities with the application of high-level industry AI-based concepts such as smart industry, smart city, intelligent transportation, and smart health.

This layered architecture is represented in Figure 2. Therefore, we see the ubiquitous use of AI throughout the B5G/6G networks associated ecosystem.

Considering other work on architecture, the authors of [34] discuss four building blocks for 6G architecture from the physical layer to service layer with secure and automation of orchestrated functions. The building blocks are: 1) platform that consist of the infrastructure, 2) functional components, that covers the network operations and AI functions, 3) specialized component that enable operations such as flexible offload and slicing, and 4) orchestration to provide open service functionalities and monetization and closed-loop automation. Another work in [32] represents a four-tier 6G model with AI-enabled space-air-ground-underwater networks. The space networks consist of densely deployed satellites in different orbits to cover the under-served areas in terrestrial networks.

The architectures for B5G/6G are designed in a way to satisfy the requirements that future networks should fulfill. History shows that any upcoming generation is significantly faster in data rates than the previous generation. Though this is the centre of attention for the public, it is not the only factor determining the requirements of 6G compared with 5G. There are many metrics that are required in B5G/6G networks that should be better performing than any previous generations.

E. 6G Requirements

As mentioned, the networks in the 2030s are expected to come with much higher delivery of data rates with improved connectivity for day-to-day tasks such as faster downloads, uploads, and higher resolution streaming. It is one of the core requirements promoted to the public when a new generation of wireless networks arrives. As discussed in [4], the adoption of
6G technologies is expected to be available around the 2030s with 100 to 1000 times faster than 5G with up to terabit-per-second speeds. Also, they mention B5G/6G networks should be able to handle extremely dense connections with trillion-level objects, compared with the current billion-level. B5G/6G networks also consist of very low latencies (less than 1 ms) to support latency-sensitive future industrial applications. The following key points can be shown as the key requirements for 6G networks [32]:

- Peak data rate of at least $1Tb/s$
- User-experienced data rate of $1Gb/s$.
- Over the air latency of $10 - 100 \mu s$ and high mobility ($\leq 1,000km/h$).
- $10^7$ devices/km$^2$ connection density and area traffic capacity of up to $1/Gb/s/m^2$ for scenarios such as hotspots.
- Energy efficiency of 10–100 times and a spectrum efficiency of 5–10 times those of 5G.

The works in [31], [32] provide a comparison of metrics, and KPIs among existing generations with 6G. We summarize these metrics for 6G compared with 5G [31], [32] in Table III.

Therefore, in essence, B5G/6G networks will primarily fulfill the targets of ultra-high speeds and complex connectivity with very low latency. Many potential techniques are suggested to tackle these performance requirements, ranging from physical requirements such as using Terahertz frequency bands, improving network infrastructures, such as flexible heterogeneous networks [4] to software-based solutions.

F. Key 6G Technologies

When considering the key driving B5G/6G technologies, we can categorize them into 1) technologies that enable 6G functionalities and 2) technologies associated with 6G services. The first one is associated with fulfilling the B5G/6G requirements that are expected. These may range from hardware to software solutions that enhance speed, reduce latency,
improve overall service quality, security, privacy, etc. The second is about the technologies that will be possible to use at a large scale with the features provided by the future networks. We further discuss them as follows:

1) **B5G/6G enabling technologies:** The key driving technologies that enables 6G as discussed in [35] are listed as follows:

- **AI/ML** - Adding intelligence to B5G/6G networks will be primarily done through the use of AI. We can observe a substantial surge of AI research, starting from late 2000’s [36]. Especially this would be done with ML models when considering models significant improvement over the recent years. With the ML approaches such as Deep Learning (DL) giving higher accurate results for unseen data, using them for B5G/6G would be trivial.

- **Above 6 GHz for 6G** - The use of higher frequency bands above sub-6 GHz as a first step for B5G, and then exploring frequencies beyond mmWave, which resides in Terahertz (THz) band. This technology would be crucial to achieving the high speeds required for B5G/6G applications.

- **Communication with Large Intelligent Surfaces** - To facilitate these higher frequency bands, it is required to introduce intelligent surfaces that can optimally guide signals to reach the destination. Therefore, B5G/6G network communication will result from joint optimization of both devices and environment using Re-configurable Intelligent Surfaces (RISs) [37].

- **Edge AI** - AI-enabled capabilities will be supplemented by “collective network intelligence”, in which network intelligence is pushed to the edge to provide a distributed autonomy in B5G/6G, where AI and learning algorithms will be performed on edge devices. We will further discuss this in Section V.

- **Integrated Terrestrial, Airborne, and Satellite Networks** - To enhance the range of future networks, drones and terrestrial infrastructure will be used, and they will be connected with Low Earth Orbit (LEO) satellites for wide area coverage.

- **Energy Transfer and Harvesting** - B5G/6G network base stations will be able to provide basic power transfer for devices, particularly implants and sensors. This makes it a promising solution for powering future Internet-of-Things (IoT) devices [38].

- **Beyond 6G** - A set of technologies at early stages at present will be matured with the arrival of B5G/6G. They will be helpful in the research and standardization efforts such as security, privacy, and long-distance networking capabilities for future networks.

Considering the intelligence that will be added as a core feature in B5G/6G, AI usage will not be limited to performance improvements. However, the vision for 6G wireless networks [32] is to achieve an autonomous ecosystem with human-like intelligence and consciousness, with numerous ways to communicate and interact. Therefore, integrating AI to the B5G/6G is a crucial improvement required to perform complex tasks that require a high level of intelligence.

2) **Technologies associated with B5G/6G services:** There are many associated technologies with B5G/6G services, which will be further discussed in Section V under privacy issues. To describe briefly, we see many novel approaches and applications such as Virtual and Mixed Reality, haptics, nanorobots, holographic applications, etc. They will require much faster data rates as a base requirement. These applications demand a multi-dimensional, fully immersive experience with realistic graphic rendering in very high picture quality, controlling millions or billions of small IoT sensor devices or robotic swarms in real-time. Also, currently, trendy technologies like blockchain, Terahertz, and visible light communications will be more mature and be closely used with future networks.

**G. Visionary 6G Applications**

The introduction of 6G will boost the current technological society, industry, and people’s interactions with the ultra-fast data rates and seemingly real-time experience. There are many applications associated with B5G/6G networks. The work in [39] describes the following prospects and applications for 6G: super-smart society, Extended Reality (XR), Connected Robotics and Autonomous Systems, Wireless Brain-Computer Interactions, haptic communication, smart healthcare, and biomedical communication, automation, and manufacturing, Five Senses Information Transfer, and Internet of Everything. The authors in [35] also describe four driving applications of 6G: multi-sensory XR applications, connected robotics and autonomous, wireless brain-computer interactions, blockchain, and distributed ledger technologies. The work in [15] also describes some of these applications mentioned above and others, including industry 5.0, autonomous vehicles, UAV-based mobility, smart grid 2.0, holographic telepresence, and personalized body area networks.

Therefore, we can identify these applications as available in different application areas such as entertainment, healthcare, transportation, energy, finance, and industrial automation. Consequently, we see the impact of 6G will be available in almost every segment of daily tasks, and B5G/6G will be an essential and integrated component of people’s lives.

**III. TAXONOMY AND PRIVACY GOALS**

The term privacy is generally known to be the assurance that individuals get the control or influence of what details related to them may be collected and stored and by whom and to whom the information may be disclosed [40]. It is the capability that a person gets to seclude the information about themselves selectively.

Understanding the categories of privacy is essential to identify potential privacy-related aspects in B5G/6G networks since the possible privacy threats may fall into these categories. The following section provides an overview of the taxonomy of privacy and its relation with B5G/6G networks.

**A. Privacy Taxonomy**

Privacy consists of psychological and social background, as it is based on personal interests and their social influence.
In [41], the authors identify five privacy needs for six types of privacy: solitude, isolation, anonymity, reserve, intimacy with friends, and intimacy with family. The five privacy functions are autonomy, confiding, rejuvenation, contemplation, and creativity. Considering the B5G/6G, we can consider these functions: 1) autonomy presents right for self-governance of a particular entity, whereas, in B5G/6G networks, this could be considered in legal parties to allow services to operate freely, as long as they agree on specific evaluation criteria on privacy, preferably at a larger scale such as in a global, which is currently not available. 2) confiding is the trust that users may keep when sharing their personal data with a third party, assuming they do not share them adversely. However, currently, there is no unified approach for monitoring these third parties, beforehand but penalizing them during a break of such trust occurs. 3) rejuvenation can be considered in the context of B5G/6G as the ability to recover from a privacy breach in the networks or service providers and mitigate the adverse effects. However, the time frame and the severity of recovery could depend on many factors such as the type of data exposed, the quantity, exposure period, system capabilities, etc. 4) contemplation can be considered the investigation of potential privacy issues in the services or network to mitigate any privacy exposures. 5) creativity is required to provide potential solutions for privacy issues detected in the B5G/6G that uses existing technologies or create new ones to protect against privacy leakages.

The work presented in [42] defines seven types of privacy as follows:

- **Privacy of the person** - right to keep body functions and body characteristics (e.g., genetic codes and biometrics) private.
- **Privacy of behaviour and action** - the capability to behave in public, semi-public or one’s private space preserving privacy.
- **Privacy of communication** - avoid the interception of communications.
- **Privacy of data and image** - ensure that users’ data is not automatically available and controlled by other individuals and organizations.
- **Privacy of thoughts and feelings** - the right not to share people’s thoughts or feelings or to have those thoughts or feelings revealed.
- **Privacy of location and space** - individuals have the right to move about in public or semi-public space without being identified, tracked, or monitored.
- **Privacy of association** - people’s right to associate with whomsoever they wish, without being observed.

Considering the users in the B5G/6G networks, their data holders, such as network components and third-party services, and potential adversaries, the privacy actions needed to be taken should be different. The work in [43] divides the taxonomy of privacy in different actions occurring to the user or the data subject. Figure 3 illustrates these actions and their components. We discuss these actions and their relation with the B5G/6G networks.

1) **Information Collection**: Third parties can collect user information for different reasons, including personalization and advertising for marketing purposes [44]. This may happen via surveillance, through watching, listening to, or recording individuals’ activities through various methods such as click-through rates [44]. Another option is interrogation, through multiple means of questioning or probing for information.

This information can be collected from users directly via user devices by third-party services operated in the B5G/6G networks. The collection of information will be done through various sensor devices and personal devices such as mobile phones. A large quantity of data collection will be possible in B5G/6G compared with the current network capabilities due to the higher data rates provided in terabit speeds. Also, they will have intelligence-enabled in the collection points, which will be smart to capture only the essential information that could expose user privacy.

2) **Information Processing**: The use, update, and manipulation of already collected data can be considered as the information processing [43]. This can be used to get insights on the generators of data since, through processing, it may be possible to trace the origins and their links by connecting data. The work in [43] further divides the information processing into aggregation, identification, insecurity, secondary use, and exclusion.

The B5G/6G networks will be able to process data even from the edge devices with integrated intelligence. Also, from the architecture of B5G/6G defined in Fig. 2, we can expect tremendous processing of data in the data mining and analytics layer of B5G/6G. For this, AI tools will be used to get insights into complex, big data, which could reveal patterns that expose user privacy.
3) Information Dissemination: This refers to the revealing of personal data or the threat of spreading of information [43]. The dissemination may include the breach of confidentiality, disclosure, exposure, an increase of accessibility, blackmail, appropriation, and distortion of information [43]. These potential privacy threats come from a third party accessing the stored information. Therefore, these issues may be mitigated by adequately keeping information with proper access rights. The next problem arises when using third parties to store information, such as cloud storage providers. They may be able to access this information due to various reasons such as poor security measures, hacking, stolen media, deliberate or unintended access by employees, accidental publishing, etc.

The 5G/6G networks may also be vulnerable to uncontrolled information dissemination due to a lack of regulations for future data types and technologies and loopholes in the existing laws. Also, there is currently no unified approach to solving information dissemination issues.

4) Invasion: This involves harm caused to the user, and it does not necessarily involve information [43]. The authors in [43] categorise the invasions into two, intrusion and decisional interference. Work in [45] shows that intrusion can be detected from abnormal patterns of system usage. [46] identifies three intrusion detection methods: signature-based, anomaly-based, and hybrid systems for 4G and 5G cellular networks. The latter, decisional interference involves the governmental interference with people’s decisions [43].

The invasions would be a definite threat to privacy in B5G/6G networks. The systems may not be designed by keeping privacy integrated into their systems, especially when considering edge devices and networks. It is much possible due to their lack of power.

In terms of privacy types for 6G networks, [9] categorizes privacy aspects into data, personal behaviour, action, image, communication, and location.

5) Data: Data privacy represents the privacy of the stored data [29]. We observe users store their personal and sensitive data on mobile devices as mobile phones are easily accessible. Therefore, these devices need more measures to protect data to avoid leaking them to a third party without user consent. Due to the high data rates provided by future networks, an enormous volume of data will get collected at central storage within a short period. Therefore, attackers may find it easy to exploit privacy vulnerabilities in these single data nodes. Thus, privacy is much of a concern in terms of data.

6) Actions and Personal Behaviour: People’s actions and behaviour can play a crucial role in privacy with the influence of social media. Work in [47] shows that a person’s behaviour is predictable using only the information provided by people around them in a social network. This includes information for a third party to jeopardize user privacy. Even when a user leaves the social network, their “shadow profile” will still be available through their friends’ data. The application of IoT widens the paths to track user behaviour through extended sensors in the environment. [48] uses tourist data collected from IoT-enabled areas to simulate user behaviours under different contexts and scenarios and provide recommendations. The user privacy protection may need to be considered in such systems, which can individually track users and predict their behaviours.

7) Image and Video: With the increase of influence from social media platforms, users tend to add their personal details via images and videos. Though the users are given the freedom to select who will be seeing the post, there is information that may consist in the images that adversely affect privacy that users may not be aware of. Also, video surveillance increases third parties to track users and can use them to compromise user privacy. The work in [49] discusses the existing image privacy protection techniques, including editing techniques: blurring, black-box, pixelation, masking, encryption, scrambling, and other techniques: face regions, false colour, and JPEG metadata embedding. It also shows that a balance among privacy, clarity, reversibility, security, and robustness must be maintained for public safety requirements such as identifying suspicious behaviour and knowing non-sensitive information like the number of people in a specific area. [50] presents two reversible privacy protection schemes implemented using false colours for JPEG images. The images are applied with encryption techniques to allow only authorized parties with authorization keys to reverse the false colouring. Authors in [51] propose a tool called “iPrivacy” as an automatic privacy recommendation system for image sharing from deep multi-task learning.

8) Communication: Privacy in different modes of communication is another classic yet important aspect since communication with rich media has increased drastically over the development of platforms in recent years. There is more space to have privacy leakages as different types of communication providers provide a wide range of services through voice, text, and video for users. Thus they have more options to choose from. Through IoT communication, sensor data might carry vital health signatures of individuals. The work in [52] shows that IoT platforms, with their cloud connections, pose vulnerabilities that attackers may exploit to extract useful information. It also indicates that over-privileged IoT devices and services themselves may also collect user data that may cause breaches in privacy.

9) Location: The location privacy is important for an individual since it includes details of physical locations that the person has travelled and which may also reveal the many related information including personal behaviour, financial status, habits, beliefs, interests, and even political preferences [53]. They are highly valuable data for a third party that implies moving objects, spatial coordinates, current time, and other unique features [54]. A person should have the right of control over who will access this information unless it is not harming any public interest. Many recent work show the importance of location privacy [53]–[55]. Location-Based Services (LBS) have ever-increasing popularity, and they consist of components: a positioning system, users, networks, LBS server content provider, and a location privacy server [55]. These components are interconnected together to provide the LBS. The authors show that an adversary can attack any of the components in the network, location privacy server, LBS server, or from the user side. [53] provides many existing Location Privacy Protection Mechanisms (LPPM) considering
privacy, utility, and performance aspects. In addition, IoT systems are also vulnerable to location-based privacy issues [54], since they may include components that can sense location.

B. 6G Privacy goals

As it is clear that 5G and B5G networks can handle vast amounts of data for many recently discovered technologies, it may potentially be subjected to privacy leakages due to the complexity of this large data and wide range of services. Potential issues in privacy can go undetected in these latest technologies and new services. For example, considering edge computation, with limited capability and lack of privacy protection, it could be possible for an adversary to exploit these issues on a large scale due to more-than-ever inter-connectivity of the new generation networks. Therefore, we propose a set of privacy goals that need to be achieved to ensure these networks are trustworthy for general users. In [9], authors provide open challenges for privacy for 6G. The work in [28] defines a set of objectives for privacy in 5G networks. By extending this information, we provide our privacy goals for B5G/6G as follows:

1) Ensure of privacy-protected big data: The amount of big data is ever-increasing with recent developments such as digital and cloud storage, IoT, and network. Therefore we can identify that B5G/6G networks contribute significantly to big data. Privacy should be considered in each stage; data generation, data storage, and data processing. Figure 4 shows these stages and possibility of attacker to exploit the process [56]. However, the work to enhance privacy in big data may not suffice the rate at which it is generated. There are existing techniques for big data privacy, including HybrEx, k-anonymity, T-closeness, and L-diversity [57]. Yet, more solutions for privacy enhancement should be given for B5G/6G networks to ensure user trust in them.

2) Privacy guarantees for edge networks: In edge computing, the data can be processed close to or at the edge of the network. It improves the QoS and user experience. Especially, the platforms like IoT providers may not consider data privacy much due to limited power and processing capacity.

Trusting edge devices is another challenge that future networks will face. This is due to the reason that untrusted third parties can connect their devices and services to the network [58]. Therefore, we think having guarantees for edge networks is an important factor since there is an explosive increase in the number of interconnected edge devices with the 5G [59]. It will continue in the upcoming generations.

Edge AI is another crucial area rising with the edge networks, which can be used to offload decision making from cloud to the edge devices through AI. This will reduce the cloud servers’ load and reduce the traffic by filtering unnecessary data significantly. It is also used as a data privacy preservation technique through methods such as Federated Learning (FL), which will be discussed further in Section V. Therefore, with this rise of this edge intelligence, the guarantees for edge privacy should also consider safeguarding the edge AI’s privacy.

3) Achieving balance between privacy and performance of services: The privacy-preserving algorithms may cause performance degradation with the implementation in the real world through methods such as encryption [60]. This can be significant for devices with limited computation capacity such as IoT, yet it is imperative to implement privacy preservation for such systems. Achieving the right balance between privacy and performance is another goal that we can propose. One of the attempts to understand the balance in the context of IoT is in [61], where authors propose a two-step approach: first, get the trade-off between the quality of collected data and performance, second, to understand how the data quality affects adversary’s ability to infer the user’s private information. Today, AI-based techniques are used widely for general purpose applications. However, with B5G/6G, they will be utilized even more, including adopting AI for B5G/6G architecture itself. The privacy-preserved AI-based decision-making would add further overhead to the operations, which needs to perform at terabit speeds. Therefore, achieving the right balance between privacy and performance is important to maintain the proper QoS and data rates.

4) Standardization of privacy in technologies, and applications: The technologies and applications used in B5G/6G networks evolve independently. However, when considering the networks, we see they are interconnected when used in the real world. They may use their different set of protocols to communicate with each other. Therefore, we propose a proper standardization of security mechanisms to ensure privacy protection during communication and interfacing these technologies. This could be considered especially when interfacing with edge devices, as they are more vulnerable to privacy

![Fig. 4. Big Data System and Privacy Considerations on Different Stages of Operation](image-url)
leakages. [28] also shows that harmonizing privacy services in the global context to promote a digital single market is an important objective for B5G/6G networks.

5) **Balance the interests in privacy protection in global context:** To achieve standardization efforts, it would be an ambitious goal to make a global level understanding of the importance of privacy protection, satisfying the interests in fostering privacy services at a global level. The systems such as human rights mechanisms might support this, yet insufficient alone and more protective standards should be implemented for cyberspace activities [62]. It also summarizes a set of actions or requirements an effective legal regime should take to ensure privacy in cyberspace:

- Define the rights of individuals and rights of data controllers.
- Provide legal means of privacy protection for individuals.
- Protect individuals from unauthorized privacy violations.
- Impose on service providers obligations to ensure lawfulness in the data processing.
- Make sure individual rights are not diminished when processing data in a state having incompatible obligations in the legal system.
- Be easily accessible and understandable.

However, it is also essential to maintain the balance between privacy requirements and industry when imposing regulations in this case. The studies in [63] show that websites have substantially reduced their interactions with web technology vendors after General Data Protection Regulation (GDPR) is effective. Also, they mention that many firms undergo losses while major players significantly increase their market shares. This makes the market less diversified and raises the barrier of entry. The authors in [64] discuss the requirements and provide references on how organizations should consider being compliant with GDPR, such as proper distinguishing data controllers and processors, transfer of personal data with third countries or international organizations, independent supervision, and penalties. It implies a substantial effect on industries and complications in handling organizations’ data with third parties.

6) **Achieving proper utilization of interoperability and data portability:** Data portability is the ability to easily transfer data from one system to another without re-entering data. This would ease a consumer’s life since they can avoid the redundant task of entering data in multiple applications.

We observe recent collaboration to enhance interoperability among companies, including Google, Microsoft, Twitter, and Apple. They have initiated a Data Transfer Project to allow individuals to transfer their data between online service providers [65]. It is an open-source project to extend data portability beyond a user’s ability to download a copy of their data from their service provider, providing the user the ability to initiate a direct transfer of their data into and out of any participating provider. It shows that it is crucial to consider privacy principles of data minimization and transparency, with clear and concise data to transfer data among such systems. The project is implemented using adapters that convert various proprietary data formats to a small number of canonical forms or data models [66]. This helps achieve data portability. It is easier to fulfill privacy requirements for a single type of data in each organization than different data types and multiple interfaces. Figure 5 shows an overview of the implementation of the project.

![Fig. 5. Overview of Data Transfer Project [66]: (a) Without Data model, adapters have to be written for communication among providers, (b) With data model, only a single API is need to be maintained for communication with any provider.](image)

However, the right to data portability remains barely known among consumers and is only implemented in a fragmented manner [67].

7) **Guarantee of erasure and rectification of personal data:** The right to erasure or the right to be forgotten is an emerging privacy requirement that is considered in legal systems [68], [69]. A person should be able to request to rectify incorrect or incomplete personal data or to erase them from the digital records [28]. The goal is to ensure this erasure. As many connected parties are involved in future networks, it is required to update all the parties on the update or erasure of this user information.

8) **Clarify the responsibility and accountability for entities processing personal information:** The transparency of data explainability is a primary requirement in B5G/6G networks, with the increased complexity of network connectivity. Also, due to the wide range of services and a large number of intermediates, it would not be easy to understand who will be responsible for users’ privacy. For instance, in the case of IoT, the work in [70] discusses the issues in IoT relevant to data deletion. It also shows that, in the case of an Ambient Assisted Living (AAL) system, it relies on various sensors and smart home appliances from different manufacturers with different communication concepts. Then, a question arises about who is the data controller. This may raise the question of who will be responsible for selecting the data controller and updating the
contents. Also, an explanation on what grounds the decision is taken regarding this may be required. We consider this is an important privacy goal to be considered in B5G/6G networks.

9) Quantifying privacy and privacy violations: Privacy is difficult to define as it is a subjective concept and has different levels from person to person, from time to time, even for the same person. Due to this nature, quantification of privacy can be difficult. However, based on the context, we may provide local standards and quantification related to different types of privacy. It may need to incorporate with other fields such as psychological aspects.

10) Achieving privacy protected AI driven automated network management operations: The B5G/6G networks should fulfill massive network traffic demands for billions of connected devices with better QoS. Network management functions automation is essential to make this a reality. Such an approach is called Zero-touch network and Service Management (ZSM) by ETSI, where the authors in [79] provide an architecture driven by AI for complete automation of management operations. However, it is also essential to regularly monitor the functionality of this automation for any privacy leakages since adversaries may find vulnerabilities in the AI models and decisions. Also, it is possible to attack these networks

| Privacy Goal | Applicability | Reasons |
|--------------|---------------|---------|
| Ensure of privacy protected big data | M | L  |
| Privacy guarantees for edge networks | L | M  |
| Achieving balance between privacy and performance of services | L | M  |
| Standardization of privacy in technologies, and applications | L | L  |
| Balance the interests in privacy protection in global context | L | L  |
| Achieving proper utilization of interoperability and data portability | L | M  |
| Guarantee of erasure and rectify personal data | L | M  |
| Clarify the responsibility and accountability for entities processing personal information | L | M  |
| Quantifying privacy and privacy violations | L | L  |
| Achieving privacy protected AI driven automated network management operation | L | M  |
| Getting explanations of AI actions for privacy requirements | L | M  |
| Ensuring Privacy of Non-personal data | L | L  |

TABLE IV: PRIVACY GOALS AND THEIR APPLICABILITY FOR Pre-5G, 5G, AND B5G/6G

| Privacy Goal | Pre-5G | 5G | B5G/6G | Reasons |
|--------------|--------|----|-------|---------|
| Ensure of privacy protected big data | M | H | H | Early version of big data concepts were appearing in early 2000s with Volume, Velocity and Variety (3V) concepts [71]. Therefore, big data is emerging from the 3G era. |
| Privacy guarantees for edge networks | L | M | H | The number of interconnected devices increased from 9 billion in 2012 to estimated 75 billion in 2020 [72], showing the increase in edge networks. |
| Achieving balance between privacy and performance of services | L | M | H | A growth of related work on privacy concerns such as in resource constrained IoT devices [72], and big data privacy [50] can be seen from the late 4G/5G era. |
| Standardization of privacy in technologies, and applications | L | L | H | Currently there are no universal standards of privacy, but the many industrialized countries are moving towards harmonizing data control practices [73]. |
| Balance the interests in privacy protection in global context | L | L | H | The standardization efforts will be challenging since not every state would be willing to agree upon a unified approach at once. We see there are no such global mechanisms for privacy yet, and existing approaches such as human rights are insufficient alone [63]. |
| Achieving proper utilization of interoperability and data portability | L | M | H | We observe recent collaborations for promoting data interoperability, and portability such as Data Transfer Project [65]. Therefore, this is relevant to current 5G, and can be expected to further increase in B5G/6G for cases such as unified digital identity [73]. |
| Guarantee of erasure and rectify personal data | L | M | H | With the growth of complexity of technology and data-exploiting businesses, the laws such as GDPR aim to address individual control on data [75] in the 5G era. This complexity and data business would increase in future with new technologies. |
| Clarify the responsibility and accountability for entities processing personal information | L | M | H | In the 5G era, we believe there are more chances of leaking personal information with the increase in edge networks, different vendor specifications [70] etc. This would clearly increase further with increased connectivity of 6G. |
| Quantifying privacy and privacy violations | L | L | H | Current work discuss on lack idea of privacy quantification approaches [76], [77] and it will be an important factor for B5G/6G to reach fully automated decision making regarding privacy aspects. |
| Achieving privacy protected AI driven automated network management operation | L | M | H | AI is increasingly used partially in 5G for applications such as automated deployments [78]. With B5G/6G, fully automated zero-touch management [79] procedures will be used. |
| Getting explanations of AI actions for privacy requirements | L | M | H | With increased AI use in 5G networks and fully AI driven B5G/6G, we see there is a requirement of providing justifications through explanations for these automated decision making. |
| Ensuring Privacy of Non-personal data | L | L | H | We observe this is emerging as a new concern which has not been carefully considered in earlier generations that focused on personal data. However, with the rise of sectors such as AI based fully automated network management and industrial adoption of IoT, we see future B5G/6G networks will need significant concern on non-personal data. |

L: Low Applicability  M: Medium Applicability  H: High Applicability
using AI to extract user information or other private details. Therefore, we suggest privacy protection is imperative when automating the network operations in B5G/6G networks.

11) Getting explanations of AI actions for privacy requirements: The users have the right to question decisions made by AI that handles their personal data. Therefore, AI used in future network operations should be explainable, and responsible entities should explain how their AI made that decision and the possible assumptions. This requires the conventional black box view for many existing machine learning techniques used today. Therefore, we propose AI explainability to be one of the most important goals in terms of privacy requirements.

12) Ensuring Privacy of Non-personal data: Non-personal data is another emerging concern for the B5G/6G networks due to the rapid addition of machine-generated data from various sources such as industrial robots, network sensing, and scientific equipment. Another form of non-personal data is the anonymized data of individuals, which were used to be personal data [80]. We further discuss non-personal data in Section VI. The growing non-personal data will inherently create the requirement of ensuring privacy. Though they are not directly related to individuals, there could still be potential threats to people, especially for industries or organizations that generate these data. They might reveal sensitive individuals’ or confidential organizational details if a third party carefully analyses this data. Hence, we consider it an important goal that should be fulfilled for the next generation of wireless networks.

In Table IV, we give a summary of privacy goals to show their applicability in pre-5G, 5G, and B5G/6G.

IV. 6G PRIVACY CHALLENGES AND ISSUES

Figure 6 shows an overview of the distribution of privacy goals, privacy challenges, and issues in the B5G/6G architecture. Here, we identify several actors involved in the architecture, end-users, developers, and attackers. The end-users generate data, developers consume this generated data to derive solutions for industry or B5G/6G-related requirements, and attackers attempt to obtain this data illegally through adversarial methods by attacking either the network or the user devices. There is a possibility for them to attack industries as well, however is not shown in the figure as it is not directly related to B5G/6G.

In Figure 6, the end-users interact with their user devices, such as smartphones or sensors, to generate private or personal data. Industries may use and store this data locally for their requirements, threatening user privacy. This data is forwarded to the intelligent sensing layer of the B5G/6G network, where we have identified key privacy goals and issues related to this layer and added them. This data is processed and/or forwarded to the data mining and application layer. There, they are stored and analyzed to harness more data related to user privacy. On top of that, we find several privacy goals and issues involved. Next, the stored or analyzed data is utilized or handled by the intelligent control layer. The smart application layer then obtains the control layer’s data to interact with the external industry or services. Industries or services may forward this data to users to interact with. Several goals and issues are related to all layers, which are summarized in the cross-cutting layers.

The next generation B5G/6G networks are expected to provide five application scenarios: Enhanced Mobile Broadband Plus (eMBBBPlus), Big Communications (BigCom), Secure Ultra-Reliable Low-Latency Communications (SURLLC), Three-Dimensional Integrated Communications (3D-InteCom), and Unconventional Data Communications (UCDC) [81]. We see a significant improvement and a lot of expectations on B5G/6G that directly impact people’s daily lives. Therefore, we propose privacy issues, which should be considered in all layers of these future networks.

A. New technology applications with privacy requirements

1) Introduction to the Issue: B5G/6G network capabilities provide an arena for many associated new technologies to the consumer market. We can see extended features such as AI-based services, edge computing, quantum computing, optical wireless communication, hybrid access, and tactile services [12]. A wide range of service ecosystems will appear for public users through these technologies. These services may help enormously users’ daily routine tasks and open new opportunities for businesses. The services can be delivered through Ultra-reliable and Low Latency Communication (uRLLC). However, they may pose a high privacy threat if their data is leaked to a third party through loopholes available in privacy measures of these new technologies. Many of these technologies are relatively new and have less research background in terms of privacy.

2) Related Work: The work in [6] mainly discusses B5G/6G associated technologies of extended reality/digital twin, tactile interaction, space-air-sea communications, smart medical nano-robots, autonomous driving, and holographic telepresence. It shows that the XR/digital twin suffers from biometric data and physical movements. In addition, [82] indicates that in XR, a variety of data types can be collected. This could include real scene information, biometric data such as gait, eye or head movements, body appearance, domicile information, heart rate, inferred emotional states, and potentially many more. Also, [82] shows that domicile data, for instance, may include a record of household objects to build a psychological profile about individuals. Tactile interaction is also vulnerable to exposing biometric data as discussed in [6]. They also show communication in the space-air-sea makes location tracking and identity exposure. Another area they discuss is the nano-robots for medical applications, which may be subjected to exposing individuals’ health information. For autonomous driving, the paper [83] discusses that an individual’s location can be tracked, as well as future location interests can be predicted using data from these vehicles. The work in [84] proposes two models of autonomous vehicles, self-contained and interconnected vehicles, with the latter being more vulnerable to privacy leakages, including the collection of vehicle sensor information through vehicle to vehicle communication. Also, [85] provides details on four different aspects of privacy-invasive technologies:
The ubiquitous capture of data in the public
- Physical surveillance by a privately owned company
- The ability to scale without additional infrastructure
- The difficulty of notice and choice about data practices for physical sensors that capture data about non-users

The study in [86] shows autonomous vehicles track the environment through their sensors and collects detailed data that users otherwise might not be shared. Holographic telepresence can expose personal behaviour, habits, and biometric data as shown by [6]. The work in [8] provides technologies of molecular communication and mentions malicious behaviour, encryption issues, and authentication cause privacy issues with the technology. They also discuss quantum communication privacy issues like encryption. The blockchain-related privacy concerns are provided as authentication, and access control, by [8]. Further issues on the blockchain are discussed in [87], where they show de-anonymization and transaction pattern exposure as privacy threats. The work in [88] shows that the distributed ledger provides privacy issues as users all share the same data. The authors of [6], [8] give a set of technologies
associated with 6G networks. The Table summarizes the potential privacy issues of these provided new technologies related to B5G networks.

3) Summary and Our Opinion: From the related work, we summarized a set of privacy issues for associated technology changes that will be built on top of B5G/6G. We observe some technologies, such as autonomous driving, already consist of a significant study of potential privacy issues. This could be due to the availability of these concepts for a long time and evolution from pre-5G era. However, others may require further investigation on privacy since they are new concepts and early stages. The applications of these associated technologies are tremendous for the public, but their impact on privacy should be regulated.

B. Privacy preservation limitations for B5G/6G control layer architecture

1) Introduction to the Issue: After considering the associated technologies and their ecosystem, we focus on the B5G/6G architecture itself for potential privacy issues. The B5G/6G control architecture is composed of many novel features, including AI-based zero-touch network orchestration, optimization, and management. These features are essential in fulfilling the ultra high-speed requirements of future networks and serve billions of highly interconnected devices. As the control architecture of networks evolves, it is important to consider the privacy strengths and potential weaknesses of future architectures. We see many privacy issues emerge in previous generations, as described in the introduction of this section above.

2) Related Work: We see B5G networks have privacy issues related to existing 5G networks and privacy concerns associated with AI. To achieve fully automated network management, the authors in propose an AI-driven ZSM architecture for B5G/6G. The authors also show that ZSM could cause privacy issues through AI models used in the ZSM systems by adding adversarial examples for training and test data. Also, they show that safe shared learning through data sharing between multiple mobile operators is essential for speeding up the accuracy of ML models. Still, it is limited due to potential privacy leakages.

3) Summary and Our Opinion: The work on B5G/6G architecture are currently at their early stages and consist of ideas from the existing tools. They promise intelligence on top of the existing architecture of 5G to manage network operations efficiently. We see a great interest in AI in future network control. However, having AI integration opens these networks to issues related to AI privacy with these future networks. Therefore, it is critical to investigate privacy requirements further when using these in the automation of networks.

C. AI models privacy attacks

1) Introduction to the Issue: As discussed in the previous two privacy issues, AI models will be used extensively for B5G/6G architecture and their associated applications. Therefore, it is crucial to identify privacy attacks that could be possible on AI models. The systems that use AI techniques such as machine learning could be subjected to attacks named adversarial attacks, where an attacker gets details on machine learning models and the data used to train the models. The solution proposed to this issue is called adversarial machine learning. Another issue arises from AI models themselves. The machine learning models can learn from big data and predict patterns and trends. If these trends could reveal
sensitive information on individuals, then it is a privacy issue, which an AI model makes.

2) Related Work: We can find many work associated with AI model vulnerabilities for different categories of AI. These categories include machine learning, reinforcement learning, deep learning, vision, etc. In [7], the authors provide a classification of different types of attacks on ML models, which is presented in Figure 2, where ML is a subset of AI. We can observe that ML attacks can be launched in both training and testing phases from the figure. The training phase can poison the input data to make the model less accurate or vulnerable to privacy attacks. An adversarial test poisoning attack is a poisoning attack that happens in the testing phase. Also, during the testing phase, an adversary can make reverse attacks where they reverse-analyze the model. A membership inference attack is used to infer whether a particular member is included in the training data [7], which violates the privacy of that member. The work of [91] shows that DL is vulnerable to poisoning attacks in the training phase and model extraction, model inversion, and adversarial attacks in the testing phase. Among them, they highlight model extraction and model inversion attacks invade the models’ privacy, where the former focuses on model information and the latter tries to extract training data. Another type of attack is the attribute inference attack, where attackers target sanitized data released by the data owner to infer the attributes of the data [92], rather than only inferring the membership. Therefore, an attacker of an attribute inference attack would attempt to infer a user’s private attributes such as location, gender, sexual orientation, and/or political view via leveraging its public data [93]. Another one is a model stealing attack, where an adversary attempt to create a counterfeiter of the functionality of a victim ML model by exploiting its black box queries such as input and outputs, which could therefore be regarded as prediction poisoning [94]. Having AI being attacked with prediction poisoning may mislead the end users who may use it for privacy-related decision-making, leading them to decisions that compromise their privacy.

Considering the other AI categories, [95] compares several distributed RL models and shows that privacy is not guaranteed in these models since data is shared. In [96], the authors show that DRL can be used to make privacy-sensitive information leakages, proposing algorithms to infer floor plans from trained Grid World navigation DRL agents with LiDAR perception. [97] discusses NLP can be used to extract privacy violations and Personally Identifiable Information (PII), which makes it a tool for an adversary to exploit privacy-related information in documents. In computer vision, the work in [98] show that privacy concerns are surfacing since cameras can process and transfer PII at unknown extents for those who get affected.

Since AI can be used for adversarial tasks, privacy violations could be made using AI models as a tool. The work in [99] shows that AI is a “double-edged sword”, which can be beneficial in protecting user privacy if appropriately used. However, privacy violations can be made via AI. They summarise a list of such violations where these work included eavesdropping network traffic [99], load monitoring [100], de-anonymize

3) Summary and Our Opinion: We see there are various privacy issues in the existing AI categories. Some of them lack the investigation of privacy in the current status. There are numerous types of attacks possible on AI models, which may reveal the privacy of subjects used to train the models or use the trained model. Also, we see AI can be used as a tool for adversaries to launch attacks against privacy, such as revealing the identities of actual users from already anonymized data. Therefore, two points must be considered: 1) the issues with AI models, which need to be addressed before design and implementation when adopting these models for 5G/6G-related tasks; 2) the possible methods to detect AI threats to user privacy need further evaluation.
2) Related Work: Currently, there are recommendations on cloud resource usage imposed by government organizations. The updates in legal protection requirements such as GDPR advise against the outsourcing of unprotected public data to the cloud storage. Therefore, it is important to ensure data protection, and legal requirements.

The work in [103] categorizes privacy issues in the cloud into four areas by considering privacy vulnerabilities: lack of user control, dynamic nature of the cloud, privacy compliance, and accountability. They mention the issues of data loss and leakage, illegitimate data handling, illegitimate data dissemination, and unauthorized secondary usage occurs lack of user control. Data duplication and data retention occur due to the dynamic nature of the cloud. They also mention that in reality, data can be scattered in many geographical locations, and data owners may not have a clear idea of who can access it, who keeps it, and what happens when they request data deletion. A survey on sensitive data [102] mentions two requirements of privacy for the cloud: the large volume of sensitive data collected and the upgrades from data protection laws that are against outsourcing the processing of unprotected sensitive data. The work in [104] shows that data brokers could use behaviour patterns to extract sensitive information from user, which may expose sensitive details such as chronic diseases, religious interests, political affiliation, investment habits, etc. Privacy-preserving access control schemes can bring high complexity, which limits cloud services scalability and flexibility [105].

Attribute privacy is another concern in locations with big data processing. The work in [106] shows global properties of datasets (e.g., the average income of individuals in a dataset, rather than an individual’s income), can be sensitive and confidential, even though the individual data points are anonymized. These attributes may easily be revealed through data analysis. They show that revealing some global properties may leak trade secrets, intellectual property, and other information related to the data owner. This could happen even when techniques such as differential privacy (which is discussed in Section V) are applied to individual data.

3) Summary and Our Opinion: In this privacy issue, we discuss two aspects: cloud computing and cloud storage. Since these two topics are matured, there are numerous issues identified by previous work related to these two. By using cloud services to store data, one risks exposing this data to a third party, either by the security vulnerability of the cloud service provider or by the provider itself. Even when the data is secured, there could still be potential privacy leakages from the global attributes that may be revealed from the nature of datasets in the cloud. Therefore, we see that cloud computing still faces a set of numerous privacy challenges to be addressed when adopting the new 5G/6G networks, though it is a reasonably matured technology.

E. Privacy issues in edge computing

1) Introduction to the Issue: Edge computing is a paradigm aimed at solving IoT and localized computing requirements by bringing computing resources close to the ‘edge’ near the end-users. This is achieved through adding computing nodes close to user IoT networks by reducing the overhead to cloud computing [72]. With the proliferation of IoT with 5G/6G networks, edge computing will be extensively used. It is indubitably favourable for computing in the edge, rather than communicating directly with the cloud for resource-constrained devices, since it would save their energy usage, improve the QoS and reduce the network traffic. However, the privacy concerns here are very important to consider since there is a limited capability in edge computing devices to implement privacy preservation. There is a frequent availability of these edge devices in many physical locations where attackers might get easy access. Also, a malicious edge computing device or a compromised device can eavesdrop or steal user data processed through it, such as sensitive health data. Therefore, it is essential to identify these issues and mitigate them.

Fig. 8. Edge Computing Overview and Attack Scenarios on Sensor Devices and the Edge Layer

2) Related Work: There is a clear possibility of exploiting privacy-sensitive information at the edge [72]. The work in [107] summarizes a set of privacy challenges for edge computing, based on the components in edge computing: core infrastructure, edge servers, edge network, and mobile edge devices. The issues such as privacy leakage data tampering can occur in the core infrastructure. They mention that edge servers are vulnerable to privacy leakages and privilege escalation that may cause unauthorized parties to access data. Edge networks and edge devices are also vulnerable to being compromised. The authors propose lightweight data encryption methods and fine-grained data sharing systems, distributed access control, resource-constrained, and efficient privacy-preserving mechanisms to mitigate these issues. However, implementing these mechanisms raises the question of embedding privacy defensive features for a vast range of devices [108] from various manufacturers, running different types of algorithms, with varying capabilities in processing and energy consumption. This makes unified privacy-preserving approaches difficult with this heterogeneity of edge devices.
F. Cost on privacy enhancements

1) Introduction to the Issue: In terms of power consumption and processing, the cost of privacy can be considered inevitable when implemented in the real world. As privacy enhancement techniques such as algorithms and protocols carry the extra computation, it may affect the overall performance in any system, from cloud computing to resource-constrained devices such as sensor nodes. Also, this additional computation would always result in more energy consumption on them. Even cloud computing and storage may also require privacy enhancement such that the impact of these enhancements would decrease the existing performance or operational costs of cloud services. Since we cannot fully minimize this issue, understanding the right balance between the cost and the risk is the most important aspect that we can consider here. Figure 9 illustrates the top six fines imposed by GDPR on various corporates in EU [109] by the end of 2021. From these high fines, it can be observed that the costs needed to pay for the lack of sufficient improvements of privacy are very high compared to the occasional development costs needed to implement these improvements. Therefore, lack of privacy improvements causes a significant risk of having to pay high levies for corporate organizations to cover up the privacy leakages or insufficient privacy measures.

G. Ambiguity in responsibility of data ownership

1) Introduction to the Issue: With the expansion of services associated with B5G/6G, many parties will collect, process, and store personal data. Data ownership is getting complicated with this increased number of data controllers, and a problem arises when claiming the data ownership. Many parties will process and store the data, but they would be unwilling to take responsibility when a privacy leakage happens. There is also a risk that these parties may misuse data, claiming they own it. Eventually, the consumer could be the victim of any such scenario if the responsibility is not handled correctly.

2) Related Work: One of the issues in creating ambiguity is duplication. The work in [112] raises the problem of the capability of data duplication without any change in the integrity of the original file, which could only be prohibited through legal means. They show this would make “keeper” of the data the copy’s owner unless contractually prohibited. Another ambiguity occurs when data owners have lack understanding of the laws. For example, in Australia, non-personal information such as business or commercial information is governed by the law of contract [113]. Therefore, one might misunderstand their personal business information is private to them. Having multiple stakeholders is another problem, as shown in [114], which mentions that multiple stakeholders complicate the idea of “ownership”, even without the data subject’s consent.

Even though the ownership is unambiguous, theft can be another issue for actual owners in the digital world. Data, AI models, or other intellectual property can be stolen without the owner’s consent. The adversaries may claim they own the model since it may be difficult to detect the owner once the data or models are slightly modified. Therefore, this makes the situation more complicated, with many owners claiming the ownership of data or intellectual property. There are existing methods for AI models to add unique watermarks.
in a model’s decision interface. However, the work in [115] show is insufficient due to the reduction of model accuracy and requires retraining.

3) Summary and Our Opinion: With the increased involvement of multiple parties to collect, process, and store personal data, there is an issue in who owns data, causing ambiguity among users and service providers. We see many issues in related work: data duplication, lack of understanding of legal terms related to ownership, and stealing and modification of data that leads to claims of multiple ownership. In 5G/6G networks, the issue of data ownership can be expected to rise due to having more intermediate services with multiple connectivities and new ways to collect personal and sensitive data further. Ambiguity in data ownership can increase due to several factors such as duplication, ignorance, having multiple owners, and theft. Therefore, we think this should be addressed as an issue for privacy.

H. Data communication confidentiality issues

1) Introduction to the Issue: During communication, there is a possibility that a third party reveals data communicated between the sender and the receiver. Ensuring confidentiality can be achieved using conventional End to End (E2E) data privacy solutions such as encryption, where only the intended receiver can understand the content. Since privacy is a fundamental problem, these techniques have evolved from early generations of wireless communications. However, with the involvement of several intermediate devices with 5G/6G networks, users would inevitably transmit their data from one device to another seamlessly. With the introduction of IoT, and its associated communication modes such as Device to Device (D2D) communications, data communication is increasing more than ever. Therefore, data transmission through these devices needs to have security mechanisms to prevent unauthorized parties from accessing data. At the same time, upcoming networks may require to sense the type of service the users are using to provide an intelligent, differentiated upcoming networks may require to sense the type of service the users are using to provide an intelligent, differentiated

2) Related Work: When considering IoT communication, the work in [117] mentions that the IoT paradigm lacks E2E privacy solutions. This happens since many IoT devices are resource constrained, and their cost of implementation would be high, as discussed in the privacy issue of cost on privacy enhancements. The authors in [117] also propose a control architecture for IoT using distributed event-based publish-subscribe pattern. This mechanism uses a set of brokers to relay messages from the publisher to the subscriber. Their work reflects that all the brokers in the system cannot be fully trusted, such that there could be privacy leaks. In the case of wireless sensor networks, the existing work for the establishment of E2E encryption may require high computation requirements in decryption [118]. The conventional E2E techniques may cause increased storage spaces, thus costs in cloud services, due to factors such as the inability of deduplication and compression from the encrypting side [119]. Short-range techniques such as D2D communication will be extensively used in 5G/6G networks to facilitate fast data exchange between physically proximate devices [120]. However, they may get subjected to potential privacy leakages such as location spoofing, eavesdropping, and man-in-the-middle attacks [120].

3) Summary and Our Opinion: Privacy in data communication is a fundamental requirement. However, due to cost and performance limitations, establishing secured E2E connections is challenging in IoT platforms. Even though attempts have been made to secure it, there could be possible privacy leakages and attacks on the communication. Therefore, guaranteeing E2E privacy in communication is crucial, especially with relatively new fields such as IoT and techniques such as D2D communication. There exists a significant challenge in introducing lightweight solutions in this sector due to resource limitations. Also, the application of AI seems currently lacking in E2E privacy to identify if communication privacy is ensured.

I. Private Data Access Limitations

1) Introduction to the Issue: Though a huge amount of data is generated each day, access to this data is limited due to privacy issues. Eventually, this data may get discarded without any proper use. Especially, health data generated by sensors are wasted, which would otherwise help save future lives through improved AI models for disease prediction. Most of the current machine learning models get trained on publicly available datasets, which may not represent the present situation and do not have up-to-date information. If these models could get access to private data without breaking the privacy of data owners, we would be able to achieve a more significant leap of accuracy with improved AI models. Therefore, it is an open issue to address and make data available without breaking privacy.

2) Related Work: Usually, when publishing data for public use, anonymization techniques are used to hide PIIs of individuals [121]. However, the problem lies in whether it is possible to infer individuals’ identity despite these anonymization methods. Many work show that this is possible. For example, the work in [122] matches anonymized patient-level health data with newspaper stories and infer patients’ identity. Sweeney et al. [123] identify critical information such as genomic information, details on medications, diseases of individual profiles in the Personal Genome Project by linking profile data with public records such as voting lists. In [124], the authors predict social security numbers of individuals through correlation of data from multiple sources, including data brokers and social networks. Therefore, we see correlations from other datasets applied to anonymized data to identify personal information on data subjects.

On the other hand, 5G/6G requires a large amount of timely and quality data sets for its AI models, as high accuracy models can be made through supervised learning approaches. In ZSM architecture, the authors of [79] show this requirement, mentioning the lack of 5G specific high-quality, timely, and high volume datasets due to privacy issues. They also show that the currently available generated data is synthetic and lacking completeness.
However, to fulfill this data requirement, there are potential hurdles to overcome. In particular, [125] discusses many issues on Privacy-Preserving Data Publishing (PPDP) techniques. Some of them are listed as follows:

- Less resilience of existing approaches in groups privacy preservation
- Excessive information loss due to over-generation of quasi-identifiers
- Imbalanced datasets anonymization
- Tradeoff between anonymization and data utility
- Differences of user privacy preferences for exposure of their data
- Adversaries background knowledge on data subjects

3) Summary and Our Opinion: Having up-to-date data for AI models makes them more accurate in their predictions. This will be important in 5G/6G as it heavily relies on AI-based decision-making processes and applications. However, we observe there are many issues in the existing approaches to anonymize data since it is possible to infer the identity of the data subjects through correlation. At the same time, future networks currently lack enough data due to these privacy issues. There will be a great opportunity for the progress of AI if more abundance of data is available for them to train on. If we can use private data without violating privacy, we can expect a significant development leap for B5G/6G.

J. Privacy differences based on location

1) Introduction to the Issue: Most countries should enforce legal actions and agree to cooperate to make privacy regulations effective globally. However, based on locations, the definitions of privacy would be different due to many reasons such as cultural influence, religion, government regulations, rituals, etc. Therefore, a practical challenge in solving disputes among legal entities exists in reality.

2) Related Work: We see a shift in power from the individual to the government in the recent past. It made the government handle the privacy of individuals. Meanwhile, its activities are opaque to the general public [126]. There is a discrepancy between the public safety and privacy of individuals. Especially, this is possible with the increase of measures of protection in the state, with the rise of terrorism and political unrest [126]. Therefore, we can observe that privacy measures should be customized depending on the region and based on complex geopolitical scenarios that dynamically change over time. However, there are some attempts to achieve a uniformity of privacy regulations in some areas of the globe. One such example is the GDPR, which was first proposed in 2012 [127]. It acts as the fundamental EU law on data protection and privacy regulations in the EU and the European Economic Area. However, it is only affecting a part of the world, and the existence of a law does not guarantee its implementation as some of these laws are only symbolic [127].

There is another issue in implementing privacy-based legal measures. A specific action applicable in a country may not be valid in another country due to its nature-like demographics. The work in [126] discusses a scenario of a surveillance program in Pakistan, which uses ML algorithm random forest and reaches a false positive rate of 0.18%, which would not be applicable for North America due to its larger population. Also, [128] shows that depending on the bylaw of the hosting country, data in cloud services may be protected by different jurisdictions.

K. Lack of understanding of privacy rights and threats in general public

1) Introduction to the Issue: The definitions of privacy terms and rights seem far-fetched for the general public as they could be technical and require context to be understood. In the B5G/6G era, we discussed that there would be many new technologies that come with novel modes that could collect user data, such as body movements, biometrics, and even thoughts. The privacy considerations in these cases could be more complicated, as people could be lack intuition on what possible methods could leak their privacy to an unwanted party by these new sensing methods. Though people could understand their personal information is somehow collected, they may be clueless on to which range these subtle data could analyse, classify, predict, or track each aspect of their personal lives. With the future networks, this will be increasing even further as the complexity of the interconnectivity increases. It is also coupled with billions of connections of small sensing devices, increasing intelligence in the network. Users may get some privacy terms and conditions when using services, but, in practice, they may not go through the privacy agreements they make when signing up for third-party applications and providing their personal and sensitive information. This creates an opportunity for others to collect this information and misuse them. Also, due to the uneven distribution of privacy rights, legal backgrounds, education levels, cultural influence, and many other reasons, people may have varying concerns about their privacy, making the future situation even more complicated.

2) Related Work: One of the issues people may face is the unclear terms that cause ambiguity. The survey on genetic information in [129] shows that many people are concerned about revealing their medical and genetic information. Still, they lack the understanding of the difference between privacy, confidentiality, control, and security and often seem to conflate these ideas. Also, a lack of knowledge on what actions are performed on their data by third parties is another concern.
In cloud computing, the work in [103] shows that most cloud customers do not have a clear idea about practices that data actors can perform with their private data. Also, [114] mentions that most consumers are unaware of the ways a service can collect the data and how third-parties use them. Due to length and complexity, even if they are aware of the implications, they often do not read these policies before consenting.

3) Summary and Our Opinion: The 5G/6G networks will provide capabilities to facilitate services related to a new range of technologies that can collect users’ information, potentially in every aspect of their lives. However, users may lack understanding of their privacy and rights and potential threats though they would enjoy the new experience of these technologies. Therefore, we observe some issues related to the ambiguity of the privacy-related terms and unawareness in general consumers about which actions are performed on their data by third parties. Educational systems may need to consider providing sufficient knowledge on user privacy in this digital age. The requirement of convincing the general user on privacy issues and making them aware is the responsibility of entities who use their data. Therefore, we see this issue as challenging since proper mechanisms to make it possible are currently not adopted by everyone.

L. Difficulty in defining levels and indicators for privacy

1) Introduction to the Issue: The term privacy is a subjective concept, which varies based on numerous reasons such as personal views, culture, and geographic locations. Therefore, it is highly challenging to define to what extent users need privacy guarantees or how much privacy is violated. However, such quantification of privacy would be very useful for AI in the decision-making process, as it simplifies which actions to be taken to ensure the privacy level. It will also then define which steps should be taken on privacy violations quickly. Also, the entities that describe and quantify privacy should justify their quantification. Having precise levels for privacy would inherently support the explainability of AI decisions for privacy.

2) Related Work: Having proper privacy mechanisms ensures trust in users. However, the work in [105] discusses that a standardized evaluation criterion for trust is lacking in cloud computing, and a quantitative trust computing algorithm is required to evaluate and compare the reliability of entities accurately. Lack of privacy quantification may cause problems in ensuring guarantees for user applications. Also, [76] describes that it is unclear to assign coefficients a precise quantification for the importance of privacy in a smart home. The authors in [77] discuss the drawbacks of Cyber-physical Systems (CPS) data privacy, where they show that having data privacy characterization and quantification model help assuring privacy preservation. Still, such models are lacking at the moment. They also mention the requirement of a vulnerability characterization model to identify where privacy is needed for CPS accurately.

3) Summary and Our Opinion: Quantification of privacy and privacy violations can support organizations’ decision-making process in preserving user privacy. Therefore, it will be an important achievement for B5G/6G networks if it is possible to confidently define how to evaluate privacy requirements, levels to which user data should be protected, and how much privacy is violated. However, from the associated work, we observe a lack of such attempts to quantify privacy and violations. Hence, possible methods for such definitions need to be developed significantly, and we consider it is challenging due to its complexity.

M. Limited availability of Explainable AI (XAI) techniques

1) Introduction to the Issue: We recently observed a substantial interest in AI research, especially in the fields of deep learning, reinforcement learning, computer vision, etc. AI is commonplace in daily activities, and recently, a wide range of tools are available in web-based ML as a Service (MLaaS) platforms [130]. Despite the significant development, there is a lack of understanding about these AI models’ decision-making process. These are, therefore, generally regarded as “black boxes” [131]. As discussed in Section II, 6G networks will add intelligence as a new core element to their network. This will bring back the question of justifying the decision taken by the AI models, as highly-sensitive private information will be transmitted through the network and may get processed by these AI models. In case of privacy violation by AI models, to investigate the roots of the issues, XAI techniques would be used. The concept of XAI, therefore, emerges again to explain and justify the underlying processes of these complex, mostly non-linear models when making decisions, though the field itself dates back to forty years ago [132]. We see many recent work related to XAI that attempt to describe the nature of the models in many fields, including healthcare and industrial practices [132]–[134]. However, the area of XAI for deep neural networks has emerged recently, and it is currently in its initial stage of development. Hence, there is a great challenge for B5G/6G in providing a reasonable explanation for the black-box approach in models such as deep neural networks.

2) Related Work: Considering the popularity of XAI, a survey in [135] shows there has been a significant increase in interest and a trend for XAI in recent years. However, they show that many work lack formalism in terms of problem formulation and ambiguity in definitions. The human’s role in XAI is not sufficiently addressed. They conclude by mentioning that considerable effort is required to tackle future challenges and issues in XAI. Also, the authors of [135] mention that there exists a tradeoff between accuracy and interpretability. The most accurate models like deep neural networks and boosted trees are usually not explainable. However, simple models such as linear or logistic regression are much interpretable, yet their accuracy is relatively low. Another work in [136] also mentions that the current field of XAI is “still evolving”, and one should be careful when developing and selecting XAI methods. Their survey on evaluation shows that currently used evaluation techniques are immature and focus only on human-in-the-loop evaluations. In XAI visualizations, [136] discuss two flaws: 1) the inability of human attention to deduce XAI explanation maps for decision making, and 2) unavailability of a quantitative measure of completeness and correctness of
TABLE VI
PRIVACY GOALS AND ASSOCIATED ISSUES FOR DIFFERENT ARCHITECTURAL LAYERS IN B5G/6G

| Layer                        | Privacy Goal                                           | IA | IB | IC | ID | IE | IF | IG | IH | IJ | IK | IL | IM | IN |
|------------------------------|--------------------------------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Intelligent Sensing Layer    | Privacy guarantees for edge networks                    | H  | H  | H  | H  | H  | M  | M  | M  | M  | M  | M  | M  | M  |
| Data Mining and Analytics    | Ensure of privacy protected big data                    | H  | H  | H  | H  | M  | M  | H  | M  | H  | M  | H  | M  | H  |
| Analytics Layer              | Guarantee of ease and rectify personal data             | H  | H  | M  | M  | M  | H  | H  | H  | H  | L  | M  | M  | L  |
| Intelligent                  | Achieving proper utilization of interoperability and data | H  | H  | L  | H  | H  | H  | H  | H  | H  | H  | H  | H  | H  |
| Control Layer                | Privacy protected AI driven network management operation| L  | H  | H  | M  | M  | H  | H  | H  | H  | NA | H  | H  | H  |
| Smart Application Layer      | Standardization of privacy in technologies, and applications | M  | M  | H  | M  | M  | H  | H  | H  | M  | H  | H  | H  | M  |
| Crosscutting Layers          | Quantifying privacy and privacy violations              | M  | L  | H  | M  | M  | H  | H  | H  | H  | H  | M  | H  | H  |
|                             | Getting explanations of AI actions for privacy requirements | H  | L  | H  | H  | M  | H  | L  | H  | H  | L  | M  | H  | M  |
|                             | Achieving balance between privacy and performance of services | H  | L  | H  | H  | H  | H  | M  | H  | L  | M  | L  | H  | L  |
|                             | Balance the interests in privacy protection in global context | M  | H  | H  | H  | M  | M  | H  | H  | H  | M  | H  | H  | H  |
|                             | Responsibility and accountability for entities processing personal information | H  | H  | H  | H  | M  | H  | H  | H  | H  | M  | H  | H  | M  |
|                             | Ensuring Privacy of Non-personal data                   | H  | H  | H  | H  | M  | H  | H  | H  | H  | H  | H  | H  | H  |

IA - New technology applications with privacy requirements  
IB - Privacy preservation limitations for B5G/6G control layer architecture  
IC - AI models privacy attacks  
ID - Privacy requirements in cloud computing and storage environments  
IE - Privacy issues in edge computing  
IF - Cost on privacy enhancements  
IG - Ambiguity in responsibility of data ownership  
NA - Not Applicable  
L - Low Applicability  
M - Medium Applicability  
H - High Applicability  
IH - Data communication confidentiality  
IJ - Private data access limitations  
IK - Privacy differences based on location  
IL - Lack of understanding of privacy rights and threats in general public  
IM - Difficulty in defining levels and indicators for privacy  
IN - Limited availability of XAI techniques

the explanation map. [137] shows several active issues and challenges for XAI: ambiguity in considering whether the XAI method should be starting from computers or starting from people, accuracy versus interpretability, using abstractions for simplifications and, explaining competencies versus explaining decisions.  

3) Summary and Our Opinion: The field of XAI is still evolving with a rapid phase, and there are some work mentioning flaws in existing XAI approaches. These issues include lack of formalism, ambiguity, and the tradeoff between accuracy and interpretability. For B5G/6G networks, XAI-based approaches will be highly required for proving and justifying the users’ privacy is preserved by the AI models used throughout the network. Therefore, a significant improvement on the techniques should be made to make them applicable in these future networks.

V. PRIVACY SOLUTIONS

As discussed in the previous section, the privacy issues in B5G/6G networks exist, and they have to be addressed by the period we start using the next generation of wireless networks. We propose the following approaches as solutions to address these issues mentioned. First, we give an introduction on the proposed solution. Then, we mention how the solution can be applied to the issues mentioned in previous Section [IV]. Next, the associated research done under the proposed solution is discussed. Finally, we summarize the key points of the solution.

A. Privacy-preserving decentralized AI

1) Introduction: The B5G/6G networks include intelligence-based automated decision-making as one of its key requirements, as discussed in the previous sections. Therefore, AI is one of the most impactful aspects of these networks. Many applications and features thus include AI as an essential requirement. Recently, there has been an increasing interest in decentralized learning in AI. It is an approach for an AI model to learn from different sources, which may be separated.

2) Relation to previous section: Decentralized AI has a lot of applications when considering the privacy aspect. This is a potential solution for the issue of having numerous new technology applications that utilize AI to learn from user data, yet the users’ privacy should not be violated. In the case of ML, the privacy of data is ensured with decentralized AI, where the original data does not move from the user device. Still, a local model can learn over time and improve a global model. Therefore, a decentralized AI approach would contribute to addressing the issue of Private data access limitations since the actual data is not physically transferred from the user device.
New technology applications can therefore use this approach to improve their AI models and provide a better service. Especially with IoT and privacy requirements in sensor environments, decentralized AI is emerging as a solution. This approach also helps bring the costs of processing at a centralized server, often offloading the majority of that requirement from the service to the client.

3) Related Work: There are different approaches of decentralized learning which may be applicable in different scenarios, depending on the requirement. The work in [138] provides existing decentralized learning methods for ML: federated multi-task learning and decentralized learning.

a) Federated Learning (FL): FL is a new form of AI that processes learning at the edge, using decentralized data at these devices. In [139] the basic flow for FL is provided as (Figure 10 further illustrates these steps):

- Model selection - pre-trained global model is shared with all the clients
- Local model training - pre-trained models are trained locally with individual training data
- Aggregation of local models - Trained model updates are sent to a central server to update and improve the global ML model

![Fig. 10. Process Flow of Federated Learning and Possible Attacks on Privacy](Image)

The authors in [139] also show there are different approaches of FL techniques. Some of them are given as:

- Centralized vs. clustered network topology - centralized FL still depends on a central server to manage the responsibility and collect data models. Clustered FL is designed to address the heterogeneity of clients, where an intermediate model is created among a group of clients.
- Data partition - this is divided into three sections: 1) horizontal partitioning, where homogeneous clients of the same domain contribute to training the global model, 2) vertical partitioning, where heterogeneous clients contribute to training the model; and 3) transfer FL - knowledge is transferred from trained heterogeneous model to personalized models.

![Diagram of Federated Learning Process](Image)

b) Swarm Learning: In [141], the authors introduce swarm learning, which is a decentralized form of ML that combines edge computing, blockchain-based peer-to-peer (P2P) networking, and coordination maintaining confidentiality without a central coordinator. Similar work in [138] proposes P2P exchanges without a central coordinator, where users with their personal datasets collaborate to learn together. For privacy preservation, they suggest using differential privacy [142] (which will be discussed in a later section) to guarantee that personal data cannot be inferred from user information. Here, the swarm edge nodes build models individually, improving themselves by sharing parameters in the network. Members are trustworthy and governed by the blockchain.

c) Other Approaches: A decentralized learning technique named Gossip Learning is a different approach to the above two methods. Here, the models perform random walk over the network, updating at every node they visit and merging with other models they meet [143]. The work in [144] compares Gossip Learning with FL and show that it is fully decentralized with no requirement of a parameter server. It also compares the performance and concludes that it is a highly competitive alternative to the FL due to its decentralized nature, but with some tradeoffs such as a slower convergence rate compared with FL.

For RL applications, a decentralized solution is available, which can be used especially in robotics, where a learning problem is decomposed into several sub-problems where the resources are managed independently. However, they work towards a common goal [145]. The work in [146] decentralized RL has emerged such that it includes underwater energy harvesting, and [147] uses decentralized RL in mobile robots. However, the privacy implications of this category still need to be investigated further.

4) Possible Costs of Privacy Protection: Though using different types of decentralized AI techniques is a great research aspect, we can see there are trade-offs of each of these methods as discussed. Therefore, it may be difficult to choose the best option for real-world implementations in practice. Also, suppose such an AI approach is changed to a different one. In that case, the upgrading costs might rise high since the decentralized models could be spread in millions of devices unless these devices and platforms offer a flexible softwarized approach for replacing the existing models.

5) Summary and Our Opinion: We identified many opportunities in distributed AI for future networks in the forms of
many approaches such as federated learning, swarm learning, gossip learning, and decentralized RL, the existing work on these may need to improve regarding privacy in their areas. Therefore, we have to consider the trade-off of these methods when selecting an approach. The costs of upgrading or switching to a different AI approach should be considered as well. It is clear that FL has progressed a lot over the recent years, and new areas such as swarm learning with blockchain technology are also emerging as alternatives to address existing issues in FL.

B. Privacy measures for Personally Identifiable Information

1) Introduction: For a person, their PIIs play a key role in privacy as they directly provide a way to distinguish them easily. Therefore, the protection of these PIIs is an essential requirement for 5G/6G. For instance, information such as digital imaging sharing is continuously popular with new mobile phones and advanced capturing devices, which may expose the PIIs of users. Therefore, it is suitable to consider privacy awareness in these devices and services when processing them. Also, privacy concerns are rapidly escalating, considering the increasing popularity of biometric authentications, geolocation, and ever-growing personal data in social media. New technologies would generate new modes of PII, such as holographic imaging and Brain-Computer Interface (BCI) wave patterns, which need their attention in considering privacy.

2) Relation to previous section: Having privacy measures for PIIs, therefore, help to address the previously discussed issues in Section IV for new technologies and applications for privacy requirements. Also, it may contribute to solving Private data access limitations where the data cannot be accessed due to PII. Having enough privacy measures for PII would only hide crucial information on users, which would help organizations release other non-critical information public, thus contributing to improvements in up-to-date big data sets for AI model training. We investigated potential solutions proposed and already existing to address the issues.

3) Related Work: The authorities should update users and organizations with guidelines on how it should be done to achieve privacy in PII. The authors in [148] provide a set of recommendations and existing work on the privacy of PII: a blockchain-based personal data sharing for privacy in data processing and sharing, privacy by design (this is further discussed as a privacy solution), privacy-preserving data aggregation at the owner side, privacy awareness, and differentiate between privacy and security.

When considering the privacy of PII in digital media, the work in [149] uses AES encryption to cover digital images to hide PIIs when transiting users’ attributes to a federated cloud environment. In [150], the authors implemented a library for privacy-preserving image processing operations using homomorphic encryption. The survey in [151] provides a comprehensive de-identification method in multi-media documents for non-biometric identifiers such as text, hairstyle, license plates, as well as physiological, behavioural, and soft-biometric identifiers.

In terms of future technologies associated PIIs, the works [152], [153] discuss privacy implications on mixed reality, which is an emerging technology where devices blend virtual and physical elements to create a new concept of reality. As shown by [153] Mixed reality collects biometric data such as eye-tracking, facial tracking, gait detection, emotional sentiment analysis, galvanic skin response, EEG, EMG, and ECG, which extends the list of existing PII. The work in [154] brings the idea of Privacy of Things (PoT), where they developed a privacy monitoring system for collecting, analyzing, and detecting incoming and outgoing traffic from IoT devices.

4) Possible Costs of Privacy Protection: With the use of encryption and other privacy-preserving techniques, there could be potential performance costs for PII. Another cost would be to make the public aware of the importance of PII privacy. Also, investigating future PII privacy measures for future technologies is another possible expansion we can expect.

5) Summary and Our Opinion: In this solution, we focused on existing methodologies for PII privacy protection. A set of recommendations can be provided to ensure PII privacy for users in industrial applications. Also, the current digital media should be provided with PII identification and protection. However, we see some costs for protecting PII, such as performance reduction due to privacy-protecting techniques and making the public aware of PII protection. The future PII collecting concepts may need further investigation of potential privacy threats. The work on PIIs are rapidly growing as they are crucial for privacy, and also, they are one of the most valuable yet very vulnerable types of data.

C. Intelligent management with privacy

1) Introduction: Software service architectures often use automated resource allocation and service management for load balancing and network management tasks. This can be applied for 5G/6G networks as well. The use of intelligence to automate resource and service management will be an essential requirement for future networks since optimum decisions have to be taken considering various dynamic factors at high speeds. Therefore, in the case of privacy, the services can add such intelligence to monitor the service allocation and status to identify potential threats that could endanger user privacy.

2) Relation to previous section: Using intelligence-based controlling contributes to privacy enhancements of 5G/6G control layer architecture where the resource allocation is done using automated mechanisms. This automation can help to bring down the privacy costs of the new wireless networks, as potential privacy threats could be identified beforehand and managed automatically. Proper privacy-enhanced controlling would contribute to fixing the privacy issues related to edge devices since possible privacy leakages from edge devices will be able to be detected from the intelligent controllers.

3) Related Work: Intelligent resource management operations can use AI techniques such as sophisticated, high accuracy DL for decision making. The work in [155] discusses DL techniques used in related work in wireless resource management problems, such as channel and power.
allocation, throughput maximization, and spectrum sharing. They observed two categories of DL used in this context: DRL and supervised DL. For edge node management, [156] defines an optimization problem for resource utilization and load balance for edge nodes while maintaining privacy and proposes a balanced service offloading method. The work in [157] proposes an energy-efficient resource allocation for massive IoT systems using a clustering algorithm to categorize subsets of systems.

Considering service management, the ZSM architecture proposed in [79] splits services to different Management Domains (MD), where MDs interface with each other using an inter-domain integration fabric. The separation of concerns in MDs improves privacy since they can have their data services and communicate using interfaces without fully exposing the implementations. Within the scope of each MD, they can use intelligent automation of orchestration, control, and assurance of resources and services. They also provide an E2E service for multiple domains with different administrative entities. [32] mentions that a combination of AI with existing technologies of SDN, NFV, and Network Slicing (NS) can reach zero-touch network orchestration, optimization, and management for 6G networks.

4) Possible Costs of Privacy Protection: Having high accurate AI is could be an expensive task since we have limitations on accuracy with capabilities of hardware and software used to make these models. There could be possible privacy leakages due to low-accuracy AI algorithms. Also, with offloading of services, there could be costs involved. There will be a substantial cost in designing and implementing new architectures and algorithms.

5) Summary and Our Opinion: The intelligence-based resource and service management can be done for B5G/6G networks to preserve privacy in a rapid decision-making environment. We found related intelligence application approaches such as DL-based resource management, clustering-based IoT nodes resource allocation, and domain-based ZSM management using intelligence. We see that intelligence-based solutions maintain privacy, and their design leads to privacy preservation in these related work. Therefore, significant work is done in resource, service management, and optimization. However, we mentioned some challenges due to various costs, such as architectural design and implementation and the accuracy of AI models. Using intelligence to directly manage privacy can be proposed as future work in this area. The architectural updates, use of algorithms, and combining AI would be critical factors that drive the change to improve this area.

D. XAI for privacy

1) Introduction: When using intelligence-based solutions, a reasonable explanation needs to be provided using XAI for justification of AI-based decisions, as discussed in Section IV. It is critical to privacy in future networks since users have rights, and any privacy violations could cause legal actions. The decisions may depend on how explainable and reasonable the AI decision is. Figure 11 provides an overview of how XAI can be applied for trustworthy AI in terms of privacy for B5G/6G networks.

2) Relation to previous section: The application of XAI would support convincing various parties to agree upon privacy standards, which can help mitigate privacy differences between locations. We can consider that using XAI would also help define the levels for privacy violations, with explainability of actions made when taking privacy decisions. Further investigation of XAI techniques helps bring down the limitations of availability in explanations for AI, especially considering the issues mentioned in the previous section on XAI itself, such as the lack of formalism and standardization of XAI techniques.

3) Related Work: To apply XAI in the privacy domain, we must identify which areas we want to consider in current XAI work. In [158], the authors divide the explainability space into three regions for the predictions/data in the context of the security domain: 1) explanations for the predictions/data itself, 2) explanations for covering security and privacy properties, and 3) explanations covering the threat model. For privacy applications, we have to consider data, privacy properties, and the model explanations, depending on the nature of data, privacy requirements, and complexity of the model as a privacy solution.

One of the main concerns in ensuring privacy is identifying how a particular AI model guarantees privacy. The authors in [159] introduce the concept of “explainability scenarios”, where it focuses on what type of explanation people need to understand on AI systems, rather than what an AI system is capable of explaining.

We can observe a great interest in the field of XAI starting from recent years. The survey in [136] shows many related work from 2007 to 2020 and categorizes them based on scope, methodology, and usage. Their work show more recent work have been added in recent years. They also show open-source packages for XAI have significantly improved over recent years. The work in [160] discusses that explainable RL (XRL) also should be a part of the mainstream XAI. The authors also
aim to introduce a Causal XRL Framework to merge ideas of XRL from existing work.

4) Possible Costs of Privacy Protection: One of the main costs of XAI could be its implementation cost for XAI algorithms since it involves the engineering of XAI solutions and development costs of interfaces for presenting explainability.

5) Summary and Our Opinion: XAI is an emerging field that can be used to justify AI-based decision-making. It is undoubtedly helpful regarding privacy-based AI applications since users and authorities may need reasons for how the AI models guarantee their privacy. In recent years, we have seen an increasing interest in XAI-based techniques from the associated work, which may continuously improve further. It positively impacts B5G/6G networks since AI will empower them, and thus, user privacy may depend on their explainability of actions.

E. Blockchain-based Solutions

1) Introduction: Blockchain is a decentralized and distributed public ledger technology in a peer-to-peer network [87]. In simple terms, it is a list of linked records, or blocks, which are connected with links that make it challenging to change any block after creation [161]. The blocks that store required transactions are timestamped, and encrypted [161]. As hash values for blocks are unique, fraud can be effectively prevented since modifications to a block in the chain change the hash value immediately. A new block can be added to the chain if most nodes in the network agree. We do this via a consensus method to verify the legitimacy of transactions in a block. It also verifies the validity of the block itself, [162]. Even some or all blocks of a blockchain in the network are changed, it is virtually impossible to tamper in practice. These transactions are duplicated and distributed across the entire network of computer systems. Though the implementations of blockchain have existed since 2008 with the famous Bitcoin concept [163], it has attracted great interest in the research community in recent years because of its decentralized and secured nature [87]. The application of blockchains on privacy has also made significant progress in research. Therefore, potential solutions exist, such that we can get their adoptions for B5G/6G networks.

2) Relation to previous section: Many new technologies can get support from blockchain to enhance their data privacy. We already mentioned such applications in swarm learning [141] [142] and PII [148] in previous solutions. More solutions are discussed here as well. Also, blockchain helps remove the ambiguity of data ownership, as blockchain maintains transaction details.

3) Related Work: We notice direct industrial and technological applications in the blockchain are significantly rising. In [164], the authors discuss a potential solution using blockchain for smart vehicles to enhance privacy in communication and privacy-sensitive data storage. The work in [164] uses a device called “miner” to handle communications in a privacy-enhanced manner for smart homes and uses a private blockchain for controlling and auditing. The survey in [161] shows blockchain can provide digital identities, distributed security, smart contracts, and micro-controls. They also show that it is beneficial to use blockchain for many domains, including financial, healthcare, logistics, manufacturing, energy, agriculture, robotics, entertainment, construction, and telecommunications. They show in telecommunications domain, we can achieve:

- Enhanced telecommunications service management
- Improve traceability and transparency
- Enable efficient contract management
- Support more cost-effective governance process

As technologies adopt blockchain for their privacy, recent work ensure privacy in the blockchain itself. The survey in [87] shows methodologies for identity privacy preservation techniques. These include mixing service transaction’s relationships in the blockchain, ring signature to sign the message on behalf of “ring” of members to hide the identity, Zero Knowledge Proof (ZKP) to utilize cryptography to prove a given statement without additional information leakage. They also discuss transaction privacy preservation methods: non-interactive ZKP, homomorphic encryption, and Pedersen commitment scheme, which is one of the implementations of the homomorphic commitment scheme.

4) Possible Costs of Privacy Protection: The costs for blockchain include maintenance costs for these networks, especially if the blockchain is private. There are issues in high energy consumption and computation costs for laborious calculations such as proof of work, which is essentially a consensus mechanism used in blockchain.

5) Summary and Our Opinion: Therefore, there is rapid development in blockchain, which can be applicable for many privacy preservations of applications in B5G/6G networks. Continuously improving work are also available to ensure the privacy of blockchain as well. However, there could be maintenance costs and energy consumption with blockchain technology. Yet, more work are continuously being done on addressing these issues. We see B5G/6G networks can use this tool to ensure privacy, including the use with AI applications, network communications, and data storage.

F. Lightweight encryption mechanisms

1) Introduction: Encryption is a technique to prevent unauthorized parties from accessing information by applying the mathematical function and converting it to an incomprehensible format. There will be a key to decrypt or get back the original information during that process. This will only be converted back by an entity with this valid key, which is only revealed by the party who performed the encryption. Encryption is often used in communication in networks to ensure data privacy primarily; since a third party receives
even the data, it will not be helpful as they are impossible to understand.

Since there is an apparent computational cost in encryption, it will be incorporated with a delay. As per the limitations of hardware and cost considerations such as computation capacity in network infrastructures such as IoT or cloud computing environments, there are proposed solutions for enhancing privacy through encryption mechanisms through less complex computations. It may help achieve better preservation of privacy and, at the same time, increase overall performance and quality of experience for the end-user. Therefore, B5G/6G networks need to get empowered by lightweight yet powerful encryption mechanisms.

2) Relation to previous section: Having lightweight encryption methods would support the fulfillment of privacy requirements for edge devices. E2E data communication confidentiality would be preserved during the transmission of data, which is vital for future networks. Also, it would significantly support bringing down the costs in privacy enhancements, processing requirements, and energy consumption aspects. Having a full-fledged cryptographic environment in embedded applications is not possible due to constraints such as power dissipation, area, and cost. Lightweight encryption would significantly reduce the workload on cloud computing environments as well.

3) Related Work: The work in [166] discusses lightweight cryptographic algorithms for IoT devices. They classify a set of lightweight cryptographic primitives into several categories: lightweight block cipher, lightweight hash function, high-performance system, lightweight stream cipher, and low resource devices. [165] presents a lightweight, compact encryption system based on bit permutation instruction group operation. The work in [167] presents lightweight symmetric-key-based operations for resource constrained environments to preserve anonymity and untraceability with a use case of a third-party mobile relay-based emergency detection system. [168] proposes a lightweight encryption scheme for smart home applications, supporting public key management through identity-based encryption, without certificate handling. A review of lightweight encryption schemes in [169] focused on many different schemes, and they show every technique has some advantages and disadvantages in IoT, such as the requirement of more storage but fewer computations vice versa. The work in [170] proposes a homomorphic encryption-based lightweight scheme for mobile-cloud computing.

4) Possible Costs of Privacy Protection: Lightweight encryption schemes might have a limited scope of security, which could cause privacy leakages. Also, we can see costs of network traffic due to a large number of parameters requests from a cloud server in some of the lightweight schemes since they may offload complex calculations to a cloud server. These schemes may also incorporate computation costs for encryption in low-resource IoT devices.

5) Summary and Our Opinion: There are many active types of research going on for lightweight encryption schemes. We observe most of them focus on resource-constrained IoT devices related applications. Some of them may come with privacy costs due to limited scope, resulting in more network traffic. However, they can be equally valuable for resourceful environments such as mobile or cloud computing due to their lesser utilization of energy and performance.

G. Privacy-preserving data publishing techniques

1) Introduction: Data can be modified for privacy during storage and usage in big data AI models. Different data sanitization methods are available to remove or add noise to user data, including sensitive personal information or PII. Two essential factors to consider here are to protect user privacy; meanwhile, the original data should also not be mutated too much for publishing. Not limited to data publishing, privacy-preserving techniques help enhance privacy in other data-related usages, such as storing data in an unsecured environment. The actual privacy of owners of those data would not be affected even if the data is exposed. Therefore, discovering more techniques on privacy-preserving data publishing would help future networks to improve their guarantees on privacy for their users’ data.

2) Relation to previous section: These data modification techniques would directly help in private data access issues, in which up-to-date data for AI model training and data science applications are lacking. Since third parties would not reveal the users’ identity, more data can be published by private or public repositories, given that privacy is guaranteed through these methods. It also helps reduce the ambiguity of privacy responsibility in data ownership since owning data by any party would not cause privacy issues for data contributors.

3) Related Work: There are many methods of privacy preservation for data in the associated work. Two approaches for data modification are shown by [171]: 1) data perturbation techniques and 2) anonymization. There are several anonymization techniques currently available as shown in [121]. Based on:

- Data nature - tabular, data sets, graphical data
- Anonymization approaches - generalization, suppression, perturbation, permutation
- Objectives of anonymization - k-anonymity, L-diversity, objectives based on presumptions on attacker’s knowledge

The works [121], [172] classify anonymization techniques based on 1) syntactic approaches and, 2) differential privacy. We also describe them briefly as follows.

a) Syntactic Anonymization: The syntactic anonymization modifies the input data set to achieve generalization. As shown in [173], the majority of the syntactic models are based on generalizing table entries. [121] shows several techniques for syntactic anonymization, namely: 1) k-anonymity, which is the warranty that in a series of k groups, the probability of identifying that person is less than 1/k; 2) L-diversity, which makes the maximum probability of recognizing the sensitive user information would be 1/L for L different groups, and 3) T-closeness, where the dissemination distinction between sensitive data and its values within groups does not exceed a value T. The work in [174] uses syntactic anonymization for federated learning based on \((k, k^n)\)-anonymity model.
b) Differential Privacy: The differential privacy is a relatively recent introduction of methods to privacy preservation, which first appeared in 2006 [175]. This is a technique used to maintain a trade-off between privacy and accuracy by adding a desirable amount of noise to data [175]. In [176] it is shown that using differential privacy techniques saves the user privacy meanwhile having no additional cost, and the accuracy further increases with further increase of the number of samples. Therefore, this is well applicable for the scenario of big data. In [177], the authors discuss privacy attacks on cyber-physical systems, namely: disclosure attack, linking attack, differencing attack, and correlation attack. They also discuss differential privacy applications and design requirements for smart grids, transportation systems, healthcare and medical systems, and industrial IoT systems.

4) Possible Costs of Privacy Protection: In differential privacy, as data gets subjected to noise addition, its accuracy might get lost, especially, when the data set is small. Loss of actual user information in anonymization techniques is another issue that comes as a cost for enhancing privacy.

5) Summary and Our Opinion: There are different approaches to privacy-preserved data publishing. We discussed mainly syntactic anonymization, perturbation, and differential privacy. However, there is a risk of losing data accuracy when using perturbations. We observe the current trend for privacy-enhancing data publishing techniques moving towards differential privacy, yet older techniques are also applied according to the use case.

H. Privacy by design and by default

1) Introduction: With the expanding capacity of network capabilities, big data, and technologies that capture and use personal data, general users will get subjected to an increased risk of privacy leakages in their lives. Therefore, privacy by design is an important aspect that should be considered in every step of the designing process life cycle of services, and their capability should be evaluated. Moreover, by default, these services or products should safeguard privacy requirements, even without any manual input from users. It is taking actions to protect beforehand, not after a privacy breach happened [177]. This means that, rather than having to come up with complicated and time-consuming “patches” later on, it is necessary to detect and assess potential data protection issues when creating new technology and to incorporate privacy protections into the overall design [178].

2) Relation to previous section: Privacy by design would help address the new technology applications with privacy requirements since designing applications focusing on privacy beforehand will eliminate most privacy threats. It also helps maintain privacy ensured as the general public may pay less attention to privacy rights and threats.

3) Related Work: As the self-decision-making capability of AI increases, it will get the opportunity to impact human life more. Therefore, the AI design process should be done with privacy concerns as a key requirement. The authors of [179] raise the concern that if the autonomy of AI increases, it would be difficult to maintain transparency. They mention Committee on Civil Liberties, Justice, and Home Affairs, Europe has given high-level indications for future regulations to stress the responsibility for the AI designers and developers. They should ensure the AI products are safe, secure, fit for purpose, and follow procedures for data processing compliant with existing legislation, confidentiality, anonymity, fair treatment, and due process.

Considering the design of associated technologies with 5G/6G, we can provide a set of guidelines to ensure privacy in designing. For instance, the work in [180] presents an architectural view for data protection by design compatible with EU GDPR for a use-case of an e-health application. Work presented by European Union Agency for Network and Information Security in [181] and [182] discusses some privacy by design strategies as follows:

- Minimize the amount of personal data as possible
- Hide personal data from plain view
- Separate personal data in a distributed fashion
- Processing of personal data should be done at the highest level of aggregation
- Inform data subjects with transparency
- Data subjects should be provided agency over the processing of personal data
- Enforce privacy policy compatible with legal requirements
- Demonstrate compliance with privacy policy into force and any applicable legal requirements

Figure 12 illustrates how these design strategies could be applied.

Having privacy enabled in design will automatically provide enhancements of security aspects. In fact, [148] shows that privacy by design provides two levels of security for IoT systems: 1) checking data fitness to the context when collecting information 2) capability of a system to assess the scope of data sharing to the internet and other associated risks. Similarly, in [183], the authors develop an IoT environment to help developers to engage with data protection at design time.

4) Possible Costs of Privacy Protection: There is a design cost for privacy by default implementations, coupled with an additional cost of privacy preservation techniques for implementation. Also, when updating the privacy by design schemes, there will be costs for any design changes if new standards are imposed.

5) Summary and Our Opinion: Adopting privacy by design is an essential step in assuring guarantees to privacy beforehand, rather than fixing when a privacy leakage occurs. We see an emergence in the privacy by design topic in terms of AI privacy-aware design, guidelines for design, and discussions on how privacy design helps mitigate risks. Therefore, future network architecture components, associated services, and technologies can fundamentally include privacy-protected design principles by default. However, privacy by design could be expensive to design and implement, and changes also carry costs. Hence, more work can be done to identify these costs and propose methodologies to mitigate them in the designs.
I. Techniques on privacy levels definitions

1) Introduction: As mentioned in the privacy issues in Sec. IV, we see there is an open requirement to define levels for privacy. There is a trade-off between privacy and the need for knowledge discovery [184]. This is because performing activities such as data mining for knowledge discovery might lead to revealing information, which might not be intended to be shared by the data owners. It is generally the case that no single privacy-preserving algorithm surpasses all others, and in all criteria. As a result, providing a wider analysis of a collection of metrics connected to existing privacy-preserving algorithms [184]. There is some existing work done in recent times to quantify privacy to different levels and provide metrics for privacy in certain contexts. These could build mechanisms to apply privacy for new requirements holistically.

2) Relation to previous section: Having proper definitions metrics solves the issue of difficulty in understanding levels for privacy and its violations. It may help solve legal disputes on privacy based on location since having precise metrics and quantification help convince many entities to have a common basis and agree on these definitions.

3) Related Work: As there is a lack of having proper and standardized metrics for privacy, organizations might not follow sufficient measures to protect user privacy based on various factors such as internal data mining tasks, reducing cost, and improving performance. For example, [185] shows that service providers or individuals relax privacy mechanisms to maintain a certain level of QoS. The extent to which privacy could be relaxed can be identified if privacy levels are defined precisely. One such instance is in [186], which proposes an ontology-based model for cloud providers to represent the information disclosed in a Privacy Level Agreement (PLA).

Often governments have less transparency on what data is collected from citizens in surveillance. The governments usually claim this is done for the safety of the public. However, if the public gets an agreement with the government administration on the levels, doubt in citizens about the government organizations collecting data may be compensated. Depending on the state’s safety, the levels can be lifted or relaxed, but they should be defined precisely. This may be a very important privacy step in futuristic aspects such as smart cities that are accompanied with 5G/6G, where central authorities will track massive details on user behaviour in real-time. [187] proposes a PLA to formalise a mutual agreement between a citizen and a Public Administration for transparency in data sharing and privacy needs of citizens. The work in [188] proposes a metamodel for PLA to formalise the relationships of privacy-related concepts of the GDPR.

4) Possible Costs of Privacy Protection: There could be privacy disagreements between parties due to ill-defined privacy levels. This may get subjected to legal actions or termination of contracts.

5) Summary and Our Opinion: Providing definitions and quantification for privacy is a challenging factor, as people’s perspectives on privacy could be different based on many reasons, including personal preferences. However, in 5G/6G networks, with more opportunities to exploit user privacy, there should be proper metrics to measure the privacy and provide guarantees by organizations and governments. We discussed some of the available work for privacy level definitions and agreements proposed recently. We also see an opportunity to enhance this further for future networks to be applied on a larger scale. Application of AI/XAI techniques can also be considered in this regard.

J. Homomorphic Encryption

1) Introduction: Homomorphic encryption is a new approach to allow entities to encrypt data while providing an opportunity to analyze the contents without breaching privacy. It allows mathematical operations on data to be carried out on a ciphertext, which is an encrypted form of the input data/plain text, instead of on the actual data itself [189]. It consists of three [189] forms:

- Somewhat homomorphic - supports mathematical operations for addition and multiplication, yet limited to a certain number of operations due to noise accumulation.
- Partially homomorphic - Supports any number of operations, yet only limited to a specific type of operation.
- Fully homomorphic - Support both addition and multiplication operation any number of times.
Even though the first fully homomorphic scheme was introduced in 2009, improvements are continuously carried out to make it practical to use in every platform \[190\]. Figure 13 illustrates the basic overview of homomorphic encryption.

2) Relation to previous section: This helps solve the private data access issues since private organizations can allow their data to be encrypted and out-sourced to commercial cloud environments for processing, all while encrypted. Therefore, we can consider it an existing solution for that privacy issue in B5G/6G network services.

3) Related Work: Many work exist related to homomorphic encryption. The survey in \[190\] provides a detailed description of such several homomorphic encryption methods in all three types mentioned. Their evaluation shows that the security, speed, and simplicity have increased over time, but they can improve further. They also note that fully homomorphic encryption can provide solutions for functional encryption, which controls access over data while allowing computation based on the features of identity/attribute. Yet, the related work in this area are limited. \[191\] uses additively homomorphic encryption in combination with asynchronous stochastic gradient descent algorithm for deep learning to build system with: 1) no information is leaked to the server, and 2) accuracy is kept intact. In \[192\], the authors compare homomorphic algorithms Hill, RSA, Paillier, and ElGamal and discuss applications of these algorithms in a cloud environment. They conclude that the current public key encryption efficiency is not high, and speeds need to be improved.

4) Possible Costs of Privacy Protection: Homomorphic encryption is relatively slow in operation and increased computational cost. Unfortunately, Fully Homomorphic Encryption techniques are currently more susceptible to attacks as it does not guarantee the reliability of its secret key for encryption \[190\].

5) Summary and Our Opinion: We see homomorphic encryption has a lot of applications for future networks, in terms of privacy preservation, due to its capability of processing data without decryption. This area has great attention in the research community, and there are frequently work and significant progress in this area we can observe. We consider this a potential solution for ensuring data privacy and significant progress in this area we can observe. We consider this a potential solution for ensuring data privacy for B5G/6G networks, especially addressing the Private data access limitations.

K. Regulation of Government, Industry, and Consumer

1) Introduction: Many parties in B5G/6G networks handle user data, and they could be linked with the government authorities as a mediator to oversee the actions of this data by the industry. Also, governments directly collect user data with the aid of wireless communication. For instance, using online apps by the government for contact tracing in the COVID-19 pandemic \[193\] was such an initiative. These apps may collect vast amounts of user data with high privacy-related information such as user location, identity, and medical records. If such a government system is hacked, citizens will have critical information leakages. Also, industries collect and provide data to third parties, even without the consent of users \[194\]. Therefore, the involvement of regulations helps ensure user privacy since all parties who utilize privacy-related data will require to adhere to them.

2) Relation to previous section: Regulations would support solving privacy issues related to a lack of understanding of privacy rights and threats in the general public since imposing regulations would inherently safeguard user data. Users may not require a complex understanding of their privacy requirements. Also, it may help to solve privacy differences based on location if these regulations can tackle the general privacy requirements despite the physical location. Thus, imposing these regulations should help solve the issue of legal disputes among entities.

3) Related Work: We can identify different types of regulatory approaches in the literature to address the issues. In \[28\], the authors categorize different types of regulatory approaches into three directions:

- Government regulation
- Industry self-regulation
- Consumer or market regulation

Industry and government regulations influence macro-level general privacy concerns. Their work categorizes privacy concerns to different themes regarding general privacy concerns such as: consumer attributes and privacy, macro-environment surrounding consumer privacy, technology-mediated E-Commerce privacy. The specific privacy concerns include vendor-related attributes and consumer privacy, consumer-vendor interaction, and consumer-vendor trust relationship. They finally present possible future directions for consumer privacy: through technical mediation of E-commerce privacy, individual-centered situational privacy determinants, and having a decision-environment in situational privacy. Other work in introducing privacy regulations include the work in \[195\], which proposes a framework for Intelligent Transportation Systems (ITS) from existing non-HTS technologies. They consider that ITS-specific privacy should address the four dimensions 1) who is collecting the information, 2) the potential criminal implications resulting from the collected data, 3) whether PII is being collected, and 4) whether there is a possibility of secondary collected data.

From a consumer perspective, \[196\] shows that consumers are generally aware of having privacy rights but have insufficient knowledge and resources to exercise these rights properly. They also identify consumers rely on to access privacy...
violations based on the moral values of trust, transparency, control, and access. [197] presents privacy concerns in e-commerce where they discuss that consumers are generally have limited knowledge on security and privacy and rely on laws and safety mechanisms. Therefore, introducing regulations for privacy will ultimately mitigate users from breaching their privacy.  

4) Possible Costs of Privacy Protection: These regulations may not be applicable everywhere, yet they can cause a high extra cost in implementation in only a specific region. Also, many industries may suffer financial losses if these regulations are very strictly imposed.

5) Summary and Our Opinion: With the enhanced capabilities of wireless networks, we see a requirement to regulate government, industry, and consumer privacy. The existing work suggest such approaches for each of these parties, showing where the privacy concerns arise and future directions. Also, recent work show that consumers have a general understanding of privacy, yet they lack detailed knowledge of laws and mechanisms. Therefore, the regulations imposed on the governments, industry, and consumers play a crucial role in protecting user privacy since this would ensure legal assurance for the users and their data. However, we suggest this field should need further recent work and investigation sufficing with updated regulations for the B5G/6G networks.

L. Edge AI

1) Introduction: The idea of edge AI is the implementation of AI algorithms on edge devices. This technique is helpful for B5G/6G networks because, With the ever-increasing edge connectivity, it will create huge network traffic from billions of these small devices if a central server performs AI computations on their data. Therefore, to mitigate this issue, it is inevitable to bring AI functions to the edge by offloading intelligence from the cloud to these devices to facilitate “bringing code to data, not data to code” [198].

2) Relation to previous section: Having Edge AI integrated into IoT environments may help solve issues such as latency related to edge computing. For example, an AI model trained to detect attacks on edge devices can be implemented to ensure data privacy. Implementing lightweight AI would be a requirement since we have to consider costs on performance and energy on them.

3) Related Work: The associated work further discuss the advantages offered by edge AI. The authors in [199] discuss the benefits provided by AI in the edge. The implementation includes privacy-preserving regularization and models in the context of privacy. Introducing Edge computing for AI includes fine-grained control and management of personal data ownership or decentralizing trust with blockchain [199]. Another privacy preserved implementation of edge AI is in [200], where the authors propose a privacy-preserving AI task composition framework for pushing AI tasks to the edge networks based on homomorphic encryption. [198] suggests a federated k-means clustering for edge networks with privacy preservation since the data does not leave the edge device.

Having edge AI computations may cause performance degradation on these resource-constrained devices. Therefore, considering performance improvements, there are three approaches proposed by [201]: 1) introducing power-efficient hardware processors for edge AI, and 2) Efficient software management frameworks and tools with the latest AI implementations.

The architecture of edge AI models is also important to consider in performance and separation of concerns. Indeed, [202] proposes a layered architecture for edge AI highlighting privacy concerns. It consists of two layers: 1) the application layer with user goals and business logic, and 2) the edge support layer with privacy governance facilities such as anonymization, policy enforcement, and control.

4) Possible Costs of Privacy Protection: Having AI running on edge devices may cause performance degradation of these resource-constrained devices. Attacks on these AI models could also cause privacy losses.

5) Summary and Our Opinion: The application of AI in the edge provides many benefits, including ensuring privacy, preserved intelligence, low latency for the edge devices response, and reduction of network traffic. Much recent research work is in progress to provide solutions based on AI and suitable architectures to drive the change in the direction of edge AI. We discussed such privacy preserved implementations of edge AI using associated technologies like blockchain and homomorphic encryption. This is closely connected with the decentralized AI approach we discussed, where decentralized local AI models will run on these edge nodes. Therefore, we believe edge AI would be a significant part of handling IoT, helping B5G/6G networks offload AI functions to the edge and providing users with a smoother experience when dealing with edge services.

M. Other solutions

In addition to the mentioned privacy solutions, we found other solutions that are already available, which can be used for ensuring privacy issues for B5G/6G networks. We summarize them as follows:

a) Location Privacy Considerations: Location privacy is an important aspect to consider since it is a type of PII. The establishment of location privacy measures helps solve privacy issues related to edge computing since most of the location trackers are placed in IoT platforms and mobile devices. Associated work on the discussion of location-based privacy can be applied on B5G/6G networks.

For instance, the work in [203] discusses location-based services and their privacy preservation. The authors classify and discuss them, including 1) cryptographic method Private Information Retrieval and 2) non-cryptographic approaches such as spatial obfuscation, mix zone, k-anonymity, and dummies. They suggest future research methods need to consider user-based protection and real-time protection by considering different user habits, interests, or preferences. That means they propose a personalized approach for location privacy preservation. The trajectory of locations is important since they directly include tracking user movements. For this, [204] proposes a metric called "transition entropy" that considers the privacy of users in trajectories and an algorithm to improve the
transition entropy for a given dummy-generation algorithm. Here, dummy-generation algorithms generate false location data to make it challenging to identify the user to an adversary server. However, hiding actual locations may cause difficulties for location-based personalization services to deliver accurate service. Therefore, we can see different approaches, including encrypted and un-encrypted methods for location privacy protection. Also, to ensure further privacy, techniques such as adding perturbations can be done for the location to avoid being tracked by an adversary. We can see personalized privacy can be utilized for future location privacy preferences. This can be applicable in scenarios such as contact tracing, where the work in [205] uses GPS location information for COVID-19 contact tracing from users to collect their location data, only when the user is willing to contribute. Likewise, we think that users should be given more freedom to choose. Therefore, we discuss the field of personalizing as a solution as follows:

b) Personalized Privacy: Personalized privacy is an approach to achieving privacy levels for users specialized for their requirements. Having personalized privacy may help achieve privacy issues based on different locations since no matter the location, privacy is configured based on user choices. Instead of going to a unified privacy metric, an alternative suggestion would be to rely on a personalized approach in some scenarios applicable at the consumer level since privacy preferences can differ from one individual to another. In [206], the authors show the existing privacy-preserving methods adopt a unified approach for sensing data where effective privacy metrics are lacking. They propose a personalized privacy protection framework based on game theory and data encryption for mobile crowdsensing for Industrial IoT. Similarly, the work in [207] proposes a personalized privacy-preserving task allocation framework for mobile crowdsensing, meanwhile providing location privacy. The authors in [208] evaluate the user perceptions on Personalized Privacy Assistants (PPA) for IoT, which help users to discover and control data collection practices of IoT resources. They interviewed 17 participants and recommended PPA solutions that address users’ differing automation preferences and reduce notifications, which would overload users.

Therefore, we see a potential solution for the existing privacy issue of difficulty in defining levels for privacy to be used personalization where it can be applied. However, the cost of creating platforms for personalized privacy and coordination of privacy choices of a large number of users could be high. Also, it might neither be practical nor accepted as reliable in complex decision-making situations like the government level. However, we suggest the potential for personalized privacy metrics can be investigated as a future research direction related to privacy for B5G/6G.

c) Fog Computing Privacy: Fog computing is an extra layer between the edge devices and the cloud server, acting as an intermediate entity for tasks such as filtering data and forwarding them to the cloud. Having an extra layer would reduce the cost for privacy enhancements since the fog layer can compute many intermediate functions. Only a fraction of data will be sent to the cloud, reducing both the cloud server’s overhead and the network congestion.

Therefore, in terms of privacy, fog computing could also help to preserve the privacy of IoT and the users since they minimize the need to transmit sensitive data to the cloud for analysis [209]. However, the privacy aspects within the fog node are also important to consider since data from the edge will be directly contacting the fog layer, especially in the case of an untrusted entity. Also, there is a potential risk in having a compromised fog node, which the attackers may eavesdrop on or directly modify user data.

Therefore, numerous work are available that propose privacy solutions for fog computing. For example, [210] introduces a multi-functional data aggregation method with differential privacy, based on ML for fog computing. The work in [211] uses blockchain-enabled federated learning to achieve decentralized privacy, eliminate poisoning attacks, and achieve high efficiency in fog computing. The survey in [212] summarizes some available techniques for privacy preservation for fog computing. It presents the following open challenges and future research directions: dynamic nature of fog nodes and users, malicious fog nodes, malicious insider attacks, secure communication, digital evidence of fog events, trust of end-users, and fog service.

We see fog computing as a promising bridge between the edge and the cloud. However, there exists a possibility of being attacked by an adversary to collect data from many edge devices, causing privacy breaches. However, Fog computing is a much more active area of research in terms of privacy, where associated work mention privacy enhancements that can be made with the fog nodes and the privacy of fog computing itself.

Table VII summarizes the privacy solutions, how they can be applied in the B5G/6G context, and their potential limitations.

VI. PRIVACY OF NON-PERSONAL 6G DATA

We focused mainly on the B5G/6G networks associated with privacy issues and their solutions in previous sections. It is considered critical for a general user privacy preservation, where users are the most important aspect and the centre of attention for industries, services, legal authorities, and government organizations. However, there is a huge collection of data belonging to the category of non-personal data, which needs attention to identify potential privacy threats, not specifically for natural persons, but also for industries and organizations that generate this data. Figure 14 shows categories of non-personal data and some examples in different fields.

A. Definitions

According to GDPR definition Art. 4 [213], there are two categories of data considering the linkage with the data source: personal data and non-personal data. Personal data is the data that is directly related to an individual, which can be used to identify the natural person (data subject). This could be directly or indirectly identifiable through a reference such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological,
| Privacy Solution                                      | Methodology                                                                 | Costs of Privacy Preservation                                                                 |
|------------------------------------------------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Privacy-preserving decentralized AI                  | Use of Federated Learning, and Swarm Learning                                | Difficulty in selecting of which learning technique to be used due to trade-offs               |
|                                                      | Can use other approaches such as Gossip Learning, and decentralized Reinforcement Learning | Cost in changing the use of AI algorithm if needed                                             |
| Privacy measures for Personally Identifiable Informa| Providing guidelines on PII privacy                                        | Performance costs for encryption and other techniques                                         |
| tion                                                                                       | Encryption techniques, Design principles with privacy                       | Cost for making awareness in the public                                                      |
|                                                      | Data aggregation at the owner side                                          | Research costs for detection of future technologies and possible new PII privacy measures    |
|                                                      | differentate between privacy and security                                    |                                                                                                |
|                                                      | Investigation of future technologies using new types of PII                 |                                                                                                |
| Intelligent management with privacy                  | Deep Learning for wireless resource management                              | Privacy leakages due to low accuracy AI algorithms                                           |
|                                                      | Privacy preserved service offloading                                         | Costs of offloading                                                                           |
|                                                      | Use of clustering for massive IoT networks to identify subsets               | Implementation cost of new architectures and algorithms                                        |
|                                                      | Separation of concerns using ZSM Management domains                         |                                                                                                |
|                                                      | Combination of AI with SDN, NFV, and NS                                      |                                                                                                |
| XAI for privacy                                      | Apply XAI for data, predictions, and threat model                           | Implementation cost for XAI algorithms                                                        |
|                                                      | Use of explainability scenarios                                              | Development costs of interfaces for explainability                                           |
| Blockchain Based Solutions                           | Using blockchain for privacy sensitive data storage                          | Maintenance costs for blockchain networks                                                     |
|                                                      | Privacy protected digital identities                                        | Energy, and computation costs for calculations such as proof of work                           |
|                                                      | Creating smart contracts without privacy leakage                             |                                                                                                |
|                                                      | Use of ring signatures for hiding identity of members                        |                                                                                                |
|                                                      | Zero Knowledge Proof                                                        |                                                                                                |
| Lightweight encryption mechanisms                    | Use of lightweight block ciphers, hash functions, high performance system and low resource devices | Security limitations causing privacy costs for lightweight encryption schemes                  |
|                                                      | Lightweight symmetric key operations                                         | Costs of network traffic due to large number of parameters requests from a cloud server       |
|                                                      | Public key management Identity based encryption without certificates         | Computation costs for encryption                                                               |
| Privacy-preserving Data publishing techniques         | Anonymization techniques based on syntactic approaches                      | Accuracy loss due to noise addition in differential privacy                                   |
|                                                      | Differential privacy by adding random noise to data                          | Loss of actual user information in anonymization techniques                                   |
| Privacy by design and default                        | Minimize and hide plain view of personal data usage                         | Design cost for privacy by default implementations                                           |
|                                                      | Distributed personal data storage                                           | Additional cost of privacy preservation techniques for implementation                          |
|                                                      | Processing of personal data at the highest level of aggregation             | Updating costs for any implemented design according if new standards are imposed               |
|                                                      | Facilitate transparency for data subjects                                    |                                                                                                |
|                                                      | Enforce and demonstrate privacy policy compatibility with legal requirements |                                                                                                |
| Techniques on privacy levels definitions             | Creating Privacy Level Agreements among users, general public, service providers, and the government | Privacy disagreements between parties due to ill defined privacy levels may get subjected to legal actions or termination of contracts |
| Homomorphic Encryption                               | Encrypt message and use homomorphic functions to evaluate the encrypted data without breaching privacy | Slower in operation and increased computational cost                                          |
|                                                      | Susceptible for attacks for Fully Homomorphic Encryption as it does not guarantee the reliability of secret key. |                                                                                                |
| Regulation of Government, Industry, and Consumer     | Technical mediation for E-commerce privacy                                  | Regulations may not be applicable everywhere, yet cause a significant extra cost in implementation |
|                                                      | Individual-centered situational privacy                                     | Industries may suffer financial losses due to strict privacy regulations                       |
|                                                      | Having a decision-environment for the situational privacy                  |                                                                                                |
|                                                      | Regulations on who is collecting data, criminal implications from data, if data contains PII, possibility of secondary collected data | Make consumers aware on privacy regulations                                                   |
| Edge AI                                              | Decentralized AI algorithms in edge platforms                               | Performance degradation of resource constrained edge devices                                  |
|                                                      | Privacy preserving AI models                                                | Attacks on AI models causing privacy losses                                                   |
|                                                      | Storage and process data locally reducing cloud usage                       |                                                                                                |
|                                                      | Separation of concerns, and using privacy enhanced architectures            |                                                                                                |
| Location Privacy Considerations                      | Using cryptographic and non-cryptographic mechanisms                       | Location based personalization services may face difficulty to deliver accurate service       |
|                                                      | False location generation algorithms to prevent tracking movements          |                                                                                                |
| Personalized Privacy                                 | Use of consumer preferences to adjust the level of privacy they require in using services and products | Cost of creating platforms for personalized privacy and coordination of privacy choices of a large number of users |
| Fog Computing Privacy                                | Acts as an intermediate layer between cloud and the edge                   | Possibility of being attacked by an adversary to collect data from many edge devices, causing privacy breach |
|                                                      | Handle traffic from the edge devices, perform intermediate functions, and forward reduced traffic to the cloud |                                                                                                |
|                                                      | Protects privacy of data from edge devices, can perform privacy preservation operations to enhance privacy |                                                                                                |
### TABLE VIII
Privacy Solutions that Address Privacy Issues in B5G/6G

| Privacy Solution                                                                 | IA  | IB  | IC  | ID  | IE  | IF  | IG  | IH  | IJ  | IK  | IL  | IM  | IN  |
|---------------------------------------------------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Privacy-preserving decentralized AI                                            | ✓   | ✓   |     |     |     |     |     |     |     |     |     |     |     |
| Privacy measures for Personally Identifiable Information                       | ✓   |     |     |     |     |     |     |     |     |     |     |     |     |
| Intelligent resource management with privacy                                    |     | ✓   | ✓   |     |     |     |     |     |     |     |     |     |     |
| XAI for privacy                                                                 |     | ✓   |     | ✓   |     |     |     |     |     |     |     |     |     |
| Blockchain Based Solutions                                                      | ✓   |     |     |     |     |     |     |     |     |     |     |     |     |
| Lightweight encryption mechanisms                                              | ✓   | ✓   | ✓   |     |     |     |     |     |     |     |     |     |     |
| Privacy-preserving Data publishing techniques                                   |     |     | ✓   | ✓   |     |     |     |     |     |     |     |     |     |
| Privacy by design and default                                                   |     |     | ✓   |     |     |     |     |     |     |     |     |     |     |
| Techniques on privacy levels definitions                                        |     |     |     | ✓   | ✓   |     |     |     |     |     |     |     |     |
| Homomorphic Encryption                                                          |     |     |     |     |     |     | ✓   |     |     |     |     |     |     |
| Regulation of Government, Industry, and Consumer                               |     |     |     |     |     |     |     |     | ✓   | ✓   |     |     |     |
| Edge AI                                                                         | ✓   | ✓   |     |     |     |     |     |     |     |     |     |     |     |
| Other solutions                                                                 |     |     |     |     |     |     |     |     |     |     |     |     | ✓   |

IA - New technology applications with privacy requirements
IB - Privacy preservation limitations for B5G/6G control layer architecture
IC - AI models privacy attacks
ID - Privacy requirements in cloud computing and storage environments
IE - Privacy issues in edge computing
IF - Cost on privacy enhancements
IG - Ambiguity in responsibility of data ownership
IH - Data communication confidentiality
IJ - Private data access limitations
IK - Privacy differences based on location
IL - Lack of understanding of privacy rights and threats in general public
IM - Difficulty in defining levels and indicators for privacy
IN - Limited availability of XAI techniques

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**B. Role of Non Personal Data and its Importance for B5G/6G**

With the enhanced requirements and regulations of privacy, non-personal data will be used widely in future networks, especially when considering anonymized data that were once containing personal information. Even the machine-generated or statistical non-personal data is highly important, which could be public records of government operations, general health data, machine sensor readings, meteorological details, etc. These datasets could be used heavily for AI models that work for B5G/6G networks. As we discussed in the privacy solutions section, many anonymization approaches will be used for the creation of non-personal data. Novel approaches will also be discovered when considering the possible future methodologies that could extract or trace a data subject through new data analytics approaches.

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**C. Issues and Challenges for Non-Personal Data in B5G/6G**

As non-personal data is also expanding rapidly, special attention should be given to potential privacy issues that could occur with them. We see there are different issues specific to non-personal data, which can occur due to reasons described below:

1) **Lack of precise definitions of Non-personal data:** As mentioned in the introduction to this section, the definition of non-personal data is passive, implying they are anything that is not personal data. However, this definition is criticized due to its lack of precise nature since it assumes that personal data itself is easily traceable and well defined, which is not often the case as personal data is also contingent and context-specific. Even the FFD framework does not precisely provide sufficient definitions for Non-personal data, which makes it difficult to be understood clearly. This could cause loopholes in legal requirements, and thus it could lead to privacy violations without properly addressing them. Therefore, proper definitions for non-personal data should be...
standardized in detail, as the current approaches seem to need improvements.

2) Mixing of Personal Data with Non-Personal Data: Mixing of personal and non-personal data in datasets is considered as a challenge that is posed, making it doubtful to identify the borderline between personal and non-personal data. This could affect the B5G/6G networks in the areas with previously discussed issues such as causing ambiguity in data ownership, lack of having sufficient data to train models in B5G/6G networks, due to difficulty in freeing non-personal data. It could create costs in separating non-personal data as well.

However, it could be possible to avoid this problem firsthand if a clear separation between personal data and non-personal data is made when designing. This is an approach for privacy by design that we discussed previously in Section IV. Then, it would be easy to store them separately, such that non-personal data could be used without any ambiguity.

3) Data Profiling on Non-personal Data: Even though the data is made anonymized using different techniques, there are still possible loopholes in these techniques to infer the membership of a natural person or non-human objects from these non-personal data by discovering correlations in the data from data mining techniques. With B5G/6G networks, these data profiling and mining tasks will be done heavily in the layered architecture’s data mining and analytics layer, as discussed in Section IV. Therefore, there will be intentional or unintentional membership inferences from this data. Discovering either human or non-human membership may affect the data owners and data subjects since the intention of anonymization was not fulfilled in such a case, thus causing a privacy leak.

4) Data Localization Laws: Data localization laws impose restrictions on free data movement of some countries on data of residents and data generated by corporate organizations of that country. It, therefore, clearly acts as a buffer to get access to private data, which is discussed in privacy issues in Section V, which would fall under the Private data access limitations. On the other hand, having the free flow of data would expose corporate organizations’ privacy and potentially harness privacy-related information from anonymized personal data. For example, considering the law in EU for free flow of data, it reduces the barriers of free flow by relaxing the restrictions imposed by data states on data localization to promote a digital single market. However, the privacy requirements need to be further evaluated in this regard since all states, industries, or organizations may not equally be capable of providing the proper privacy measures on their non-personal data.

D. Non-personal Data Privacy Solutions

We have discussed Non-personal data solutions comprised of anonymization techniques in Section V. Differential privacy can also be used as a solution to achieve anonymity in non-personal data, which is also discussed in the same section.

Government regulations also play a key role in standardizing non-personal data privacy considering the other solutions. Providing proper definitions standards on maintaining the privacy of non-personal data for corporates and other entities who generate or own these data, using techniques such as privacy level definitions will be helpful as mentioned in previous Section V.

VII. 6G Privacy Projects and Standardization:

Several B5G research initiatives are underway, bringing together academic and industry partners from all around the world. We describe some of such projects in this section, including a description of their major goals and planned contributions.

A. Research Projects

1) A4EU [217] - the project is aiming to build a comprehensive European AI-on-demand platform to lower barriers to innovation, boost technology transfer, and catalyse the growth of start-ups and SMEs in all sectors through open calls and other actions. The platform built as part of A4EU acts as a broker, developer, and one-stop-shop providing and showcasing services, expertise, algorithms, software frameworks, development tools, components, modules, data, computing resources, prototyping functions, and access to funding. Training is also available for different user communities such as engineers or civic leaders to obtain skills and certifications. The A4EU platform aims to establish a world reference, built upon and interoperable with existing AI and data components and platforms.

2) XMANAI [218] - EU-funded project that focuses on explainable AI. Researchers working on the XMANAI project plan to carve out a “human-centric”, trustful approach that will be tested in real-life manufacturing cases. XMANAI aims to demonstrate (using four real-life manufacturing cases) how it will help the manufacturing value chain shift towards the amplifying AI era. It is done by coupling (hybrid and graph) AI “glass box” models that are explainable to a “human-in-the-loop” and produce value-based explanations. This is done with complex AI assets management-sharing-security technologies to multiply the latent data value in a trusted manner and targeted manufacturing apps to solve concrete manufacturing problems with high impact. XMANAI pilots are carried out in collaboration with CNHi of Italy (generating a virtual representation (digital twin) of the plant based on 3d-2d models and production, logistic, maintenance data of the lines), Ford (real-time representation of production and traceability), UNIMETRIK (intelligent measurement software that warns that the point sets defined for the measurement strategy are adequate) and Whirlpool (platform capable to ensure a reliable sales forecasting for the D2C channel).

3) SPATIAL [219] - EU-funded project set up to tackle the identified gaps on data and black-box AI. It is done by designing and developing resilient accountable metrics, privacy-preserving methods, verification tools, and system solutions that will serve as critical building blocks for trustworthy AI in ICT systems and cybersecurity. The project tackles uncertainties in AI that directly impact privacy, resilience, and accountability. Similar to some of the issues identified in Section V of this paper, the SPATIAL project identifies possible
That enables protection, trustworthiness, and accountability in managing 5G network infrastructures across multiple domains. INSPIRE-5Gplus’s conceptual architecture is divided into Security Management Domains (SMD) to facilitate the separation of security management concerns. Each SMD is accountable for intelligent security automation of its scope’s resources and services. The E2E service SMD is a unique SMD dedicated to managing end-to-end services’ security. Using orchestration, the E2E service SMD manages communication between domains. Each SMD, including the E2E service SMD, comprises a collection of functional modules that work in a closed-loop fashion to provide software-defined security orchestration and management that enforces and controls security policies for network resources and services real-time.

4) STAR [220] - is a project that links AI and digital manufacturing experts towards enabling the deployment of standard-based secure, safe, reliable, and trusted human-centric AI systems in manufacturing environments. STAR will research how AI systems can acquire knowledge to make timely and safe decisions in dynamic and unpredictable environments. It will also research technologies that enable AI systems to confront sophisticated adversaries and to remain robust against security attacks. Partners working on this project consider several AI-powered scenarios and systems, including active learning systems, simulated reality systems that accelerate Reinforcement Learning (RL) in human-robot collaboration, XAI systems, Human Centric digital twins, advanced reinforcement learning techniques for optimal navigation of mobile robots, and for the detection of safety zones in industrial plants and cyber-defense mechanisms for sophisticated poisoning and evasion attacks against deep neural networks operating over industrial data. These technologies will be validated in challenging scenarios in manufacturing lines in quality management, human-robot collaboration, and AI-based agile manufacturing. STAR aims to eliminate security and safety barriers against deploying sophisticated AI systems in production lines.

5) 6G Flagship [221] - is a research project funded by the Academy of Finland that aims to realize 5G networks from the 5G standard to the commercialisation stage and the development of the new 6G standard for future digital societies. The main goal of 6G Flagship is to develop the fundamental technology needed to enable 6G. The 6G Flagship research program has published the world’s first 6G white paper [222] which opened the door for defining the 2030 wireless era. The authors of that paper identified several interesting security challenges and research questions, i.e., how to enhance information security, privacy and reliability via the physical layer technologies and whether this can be done using quantum key distribution. Additionally, the 6G Flagship project will target wireless connectivity, distributed intelligent computing, and privacy to develop essential technology components of 6G mobile networks. Finally, the 6G flagship project will also carry out the large pilots with a test network with the support of both industry and academia.

6) INSPIRE-5Gplus [223] - The project’s objective is to advance 5G and Beyond network security and privacy. INSPIRE-5Gplus is committed to enhancing security across multiple dimensions, including overall vision, use cases, architecture, integration with network management, assets, and models. INSPIRE-5Gplus addresses critical security challenges across a range of vertical applications, from autonomous and connected vehicles to critical industry 4.0. INSPIRE-5Gplus will develop and implement a fully automated end-to-end smart network and service security management framework that enables protection, trustworthiness, and accountability in its initial state, where we discussed different aspects of privacy by considering various privacy goals. We observe it is increasingly rising the requirements on privacy with the new technologies, a broad range of services, and a massive amount of data.

B. Standardization related to 6G privacy

Standardization is essential for establishing the technological criteria for 5G networks and selecting the best technologies for 6G network implementation. As a result, standards shape the worldwide telecommunications industry. Standardizing 6G has been assigned to several Standards Developing Organizations (SDOs). Standardization activities in the field of 6G privacy are summarized in the Table IX.
| Organizational Identifier | Standard Title                                                                 | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|---------------------------|--------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NIST SP 800-53 Rev. 4     | Cybersecurity and Privacy Controls for Federal Information Systems and Organizations | This publication provides a catalog of security and privacy controls for information systems and organizations. It extends ISO/IEC 27001, and complements other frameworks, guidelines, and standards to support the management of information security and privacy risks. The publication is intended for use by information systems and organizations to protect organizational operations and assets, individuals, other organizations, and the Nation from a diverse set of threats including hostile cyber attacks, natural disasters, structural failures, and human errors (both intentional and unintentional). The security and privacy controls are customizable and implemented as part of an organization-wide process that manages information security and privacy risk. |
| NIST TR 8228              | Considerations for Managing IoT Cybersecurity and Privacy Risks                 | The purpose of this publication is to help federal agencies and other organizations better understand and manage the cybersecurity and privacy risks associated with their IoT devices throughout the devices' lifecycles. This publication is the introductory document providing the foundation for a planned series of publications on more specific aspects of this topic.                                                                                                                                                                                                                                               |
| NIST SP 800-53 Rev. 5     | Security and Privacy Controls for Information Systems and Organizations         | This publication provides a catalog of security and privacy controls for information systems and organizations. It extends ISO/IEC 27001, and complements other frameworks, guidelines, and standards to support the management of information security and privacy risks. The publication is intended for use by information systems and organizations to protect organizational operations and assets, individuals, other organizations, and the Nation from a diverse set of threats including hostile cyber attacks, natural disasters, structural failures, and human errors (both intentional and unintentional). The security and privacy controls are customizable and implemented as part of an organization-wide process that manages information security and privacy risk. |
| NIST SP 800-53A Rev. 4    | Assessment of Security and Privacy Controls in Federal Information Systems       | This publication provides a set of procedures for conducting assessments of security controls and privacy controls employed within federal information systems and organizations. It extends ISO/IEC 27001, and complements other frameworks, guidelines, and standards to support the management of information security and privacy risks. The publication is intended for use by information systems and organizations to protect organizational operations and assets, individuals, other organizations, and the Nation from a diverse set of threats including hostile cyber attacks, natural disasters, structural failures, and human errors (both intentional and unintentional). The security and privacy controls are customizable and implemented as part of an organization-wide process that manages information security and privacy risk. |
| NIST 1500-42              | NIST Big Data Interoperability Framework: Volume 4, Security and Privacy Version 3 | This publication considers new aspects of security and privacy concerning Big Data, and reviews security and privacy use cases, proposes security and privacy taxonomies, presents details of the Security and Privacy Fabric of the NIST Big Data Reference Architecture (NBDRA), and begins mapping the security and privacy use cases to the NBDRA.                                                                                                                                                                                                                   |
| NIST TR 103 305-5 V.1.1.1 | Cyber; Critical Security Controls for Effective Cyber Defence; Part 5: Privacy enhancement | The ETSI TR 103 305-5 document is describing privacy-enhancing implementations using the Critical Security Controls. These presently include a privacy impact assessment and use of the Controls to help meet provisions of the EU GDPR.                                                                                                                                                                                                                                              |
| ETSI TS 103 485 V.1.1.1   | Cyber; Mechanisms for privacy assurance and verification                       | The document defines the means to enable assurance of privacy, using the conventional Confidentiality, Integrity, Availability (CIA) paradigm and with reference to the functional capabilities for privacy protection described in Common Criteria for Information Technology Security Evaluation. The document addresses privacy assurance within the context of Identity Management following the model described in ETSI TS 103 486. The present document addresses the cases where both transient and persistent identifiers are used, where identifiers are used in isolation, and where identifiers are used in combination. |
| ISO/IEC DIS 27555       | Information security, cybersecurity, and privacy protection — guidelines on personally identifiable information deletion | The publication provides a catalog of security and privacy controls for information systems and organizations. It extends ISO/IEC 27001, and complements other frameworks, guidelines, and standards to support the management of information security and privacy risks. The publication is intended for use by information systems and organizations to protect organizational operations and assets, individuals, other organizations, and the Nation from a diverse set of threats including hostile cyber attacks, natural disasters, structural failures, and human errors (both intentional and unintentional). The security and privacy controls are customizable and implemented as part of an organization-wide process that manages information security and privacy risk. |
| ISO/IEC 27007:2020       | Information security, cybersecurity, and privacy protection — guidelines on personally identifiable information deletion | The document defines the means to enable assurance of privacy, using the conventional Confidentiality, Integrity, Availability (CIA) paradigm and with reference to the functional capabilities for privacy protection described in Common Criteria for Information Technology Security Evaluation. The document addresses privacy assurance within the context of Identity Management following the model described in ETSI TS 103 486. The present document addresses the cases where both transient and persistent identifiers are used, where identifiers are used in isolation, and where identifiers are used in combination. |
| ISO/IEC 27009:2020       | Information security, cybersecurity, and privacy protection — sector-specific application of iso/iec 27001 — requirements | This document specifies the requirements for creating sector-specific standards that extend ISO/IEC 27001, and complement or amend ISO/IEC 27002 to support a specific sector (domain, application area or market). It explains how to include requirements in addition to those in ISO/IEC 27001.                                                                                                                                                                                                 |
| ISO/IEC 21332:2021       | Health informatics — Cloud computing considerations for the security and privacy of health information systems | This document provides an overview of security and privacy considerations for Electronic Health Records (EHR) in a cloud computing service that users can leverage when selecting a service provider.                                                                                                                                                                                                                                                                                                        |
| BSI PD ISO/TR 18638:2017 | Health informatics. Guidance on health information privacy education in healthcare organizations | This standard specifies the essential educational components recommended to establish and deliver a privacy education program to support information privacy protection in healthcare organizations. The primary users of this document are those responsible for planning, establishing, and delivering healthcare information privacy education to a healthcare organization. |
of data collected every day associated with the luxury of increased data rates offered in 5G and beyond networks. Also, since intelligence is added in future B5G/6G networks, there will be more opportunities for missing human supervision, thus making more space for privacy leakages. Furthermore, there are unsolved questions in privacy that we can observe in the existing 5G networks. However, we can also find potential solutions for these issues from the existing research. Furthermore, we also discussed non-personal data, which is another upcoming aspect for B5G/6G networks. The standardization efforts for privacy were also discussed. To summarize the discussions, the following subsections will briefly describe the learning of each of our discussions, the questions, and future possibilities of research.

A. Taxonomy and Goals

1) Lessons Learned: Considering the taxonomies of privacy, we have observed different approaches to categorizing privacy based on privacy needs, functions to fulfill those needs, and privacy based on different actions done on data subjects. This implies that privacy may be categorized according to different views, and there is no universal definition of privacy nor a taxonomy. Hence, it is based on different perspectives on requirements to exclude certain information and different actions done on data. The privacy goals are built from the existing 5G privacy issues and by considering AI, big data, and IoT aspects of B5G/6G networks, which will be prominent. The goals laid the foundation for the underlying privacy issues and potential solutions. We see there are more issues associated with some goals, such as ensuring big data privacy, and achieving the balance between privacy and performance, as depicted in Table IV. However, the difficulty of achieving these goals may not necessarily be depicted by the number of associated issues. We see some areas such as big data privacy have made significant progress over the recent years, as suggested by the related work. We also summarized the impact of these privacy goals in Table IV where we see pre-5G era has a lesser impact on some issues, simply due to the lack of technological background required to fulfill these goals. However, the 5G and B5G/6G networks will have greater applicability to these goals.

2) Remaining Research Questions: The taxonomy and privacy goals defined in our survey suggested following research questions may need to be addressed:

- We observe the concept of privacy is non-intuitive and subtle. This may make it difficult to understand the importance of a general user. Lack of proper resources for taxonomy and mixing privacy aspects with security would be some reasons for this.
- The privacy goals defined here need the consideration of the level of difficulty of achieving them, since some goals may be relatively easier to achieve than the others, as mentioned.

3) Possible Future Directions: When considering the privacy taxonomy, a unified taxonomy for privacy considering all the aspects of the taxonomies mentioned above and those not included may need to be developed, which can be used as a guideline in evaluating privacy requirements. When considering the achievement of privacy goals, we may need to carefully consider the associated issues, their severity, and the possibility of implementing the privacy solutions. Then the standardized set of goals for B5G/6G, specifically tailored for privacy can be made.

B. Privacy Issues

1) Lessons Learned: As we discussed, the privacy-related aspects for 6G are based mainly on three considerations. The privacy issues related to AI are the latest addition to the privacy issues. As B5G/6G is coupled with intelligence, privacy issues associated with AI will be applicable for these networks, including attacks on AI components in the network and AI as a tool for launching attacks against the network. It is also shown that privacy considerations exist in current 5G networks, which will also apply to B5G/6G. It includes the issue of non-unified privacy levels and location-dependent privacy variations. Privacy issues related to B5G/6G technologies are the other category of issues that we identified. The associated technologies rising with B5G/6G will also affect users’ privacy, especially with new types of sensors, data types, and lack of investigation on privacy on them. Therefore, we can see that privacy comes with a broad range of requirements for future networks to be addressed in these categories. We can take immediate actions on specific areas, such as the issues that are already existing in 5G networks. There are different aspects of AI-based attack scenarios that should be considered before fully adopting AI to B5G/6G since it poses risks to the network with privacy leaks. The future technologies and applications for B5G/6G may need some time for complete consideration of privacy since they evolve at different speeds, where some are mature enough and already considering privacy aspects. Still, some are at the conceptual or initial implementation stages, where privacy might not be a top priority in research and development.

2) Remaining Research Questions: Though we have considered many aspects of privacy issues applicable in B5G/6G networks, there is still space for new areas of privacy considerations that may appear over time and ones that are already available but not included. The question, therefore, exists to identify such privacy issues and their relevancy for B5G/6G. We can identify several other important questions on privacy issues remaining as:

- Identifying the impact of cross-cutting issues to each of the layers of B5G/6G networks.
- Difficulty to address the privacy issues based on location due to dynamic nature of geopolitics, demographics and other cases such as conflicts, lack of trust among neighbouring states, and cultural influences.

3) Possible Future Directions: The layered model proposed for B5G/6G networks may probably get updated with new layers added in the future. Therefore, new privacy issues may need to be added by considering them. Even the existing model can be improved; for example, when considering the intelligent sensing layer, issues related to privacy in the sensing layer may require considering both edge and fog computing and
storage requirements. When considering the data mining and analytics layer, we can implement a quantitative measurement system for privacy during a data mining task. For this, it would be possible to use techniques such as differential privacy, as mentioned, to mitigate the issues related to this layer. The intelligent control layer should be provided with better privacy measures, including privacy-enhancing techniques and explainable interfaces for AI. It appears to be the most vulnerable to attacks due to its interfacing with external applications. Also, the adoption of new applications could be done with caution with a precise set of measurable privacy thresholds before connecting with the smart application layer. As we mentioned, since third-party technology applications are evolving at different speeds, having such a defined privacy filter before the application layer would reduce the consideration of privacy measures for each new technology.

C. Privacy Solutions

1) Lessons Learned: Considering the proposed solutions, it is clear that some of them cause a higher impact over the others since we can see some privacy solutions address more issues as shown by Table VIII. Therefore, it is important to prioritize lightweight encryption mechanisms, privacy preserved decentralized AI, XAI, and intelligent management solutions. Consequently, we can also observe the higher impact of AI-based solutions and encryption mechanisms. Considering more active solutions where the current research community is active, we can consider XAI, blockchain-based solutions, homomorphic encryption, edge AI, and decentralized AI since they have more recent related work than the other solutions proposed. The regulatory approaches from governments can be implemented at a relatively easy solution but require the influences of the corresponding legal entities. Applying the privacy by design approaches would also be feasible to adopt and implement in practice, such as at industry levels, to mitigate potential privacy threats associated with new designs.

2) Remaining Research Questions: Considering the existing issues that are outside the scope of this paper and thus not included, we list the following questions remaining in privacy solutions:

- Influence on the industries, and potential economic impact due to possible frictions causing when implementing privacy solutions.
- We mentioned several costs in each privacy solution in Table VII. Their trade-offs should be further evaluated before applying these solutions to a certain privacy issue, depending on various factors, such as use-case, costs, possible technologies, etc.

3) Possible Future Directions: Some of the solutions proposed are already implemented and well studied; meanwhile, some solutions are newly introduced that have to be worked with more background check on their feasibility, considering the financial and technical capability of a certain organization implementing them. For example, blockchain is now applied practically in the real world and is continuously evolving. Also, we can see it is getting cheaper and technically much more feasible to implement since the background and infrastructure required to implement blockchain applications is reducing with the introduction of new blockchain frameworks, services, documentation, and the interest of the learning community. Similarly, we can see solutions such as differential privacy, homomorphic encryption, and edge AI applications are also increasing, based on their increasing related work in recent years. Other solutions such as new techniques of decentralized learning, personalizing of privacy, and privacy levels can be further studied to be applied for B5G/6G networks, as well as for other futuristic applications.

D. Non-Personal Data

1) Lessons Learned: We can observe most privacy-related considerations and techniques are related to personal data, where the privacy of non-personal data is under the radar most of the time. Relatively less amount of associated work on non-personal data privacy shows more evidence on this matter. However, more and more surrounding issues such as attribute privacy concerns [106], which can be incorporated with the non-personal data, could cause the revealing of sensitive details of an organization, individuals, or other private data through specific attributes by non-personal data generators. Therefore, it is essential to consider this privacy aspect in non-personal data for B5G/6G networks. This is because data generated by modes such as non-human AI based automated system logs, industrial sensor data, and many other interconnected systems would produce, and communicate non-personal data at a very large scale, due to the fast data transmission capabilities in B5G/6G.

2) Remaining Research Questions: The non-personal data considerations have the following questions to be further clarified:

- Defining further refined classification of non-personal data since anonymization techniques also have different approaches to making personal data non-personal.
- Define a standard set of anonymization techniques and criteria to create non-personal data.
- Identify potential privacy threats and attack scenarios for non-human data generators, such as automated system logs, often used in the industry.

3) Possible Future Directions: As future work, we suggest having further investigations on non-personal data definitions and privacy considerations for multi-dimensional and different types of non-personal data. For anonymization, the work in [239] suggests new techniques of anonymization schemes universally applicable for any type of data. They could be used to generate non-personal data. Also, when considering sensitive non-human data generations, further work on isolation techniques could be used to preserve this data from attacks.

E. Privacy Projects and Standardization

1) Lessons Learned: There are numerous EU and non-EU funded projects that already started to address the privacy challenges in B5G networks. Projects listed in Section VII aim to guarantee the next generation network privacy and
security using approaches beyond classical, for example XAI-based techniques to assure the privacy of future networks that play major role in most of the research projects reviewed in this paper. Projects listed above have in common, that they all consider AI-powered scenarios to approach the privacy and security concerns and it is very clear that the integrity of those solutions is going to be the greatest concern. Standards Developing Organizations (SDOs), such as NIST, ETSI, 3GPP, IETF, IEEE, and ISO, are expected to work on 6G security and privacy in the near future or already do so 6G aims to merge different technologies already standardized by SDOs. AI/ML mechanisms will have to become the main elements in 6G to achieve a satisfactory level of privacy, such as automating decision-making processes and achieving a zero-touch approach.

2) Possible Future Directions: The EU established a Smart Networks and Services Joint Undertaking (SNS) programme in 2021 with the commitment to contribute €900 million from the EU over the course of the next seven years. The goal of SNS is to enable European companies and research institutions to create research and development capabilities for 6G systems and to establish themselves as leaders in the markets for 5G and 6G infrastructure, which will serve as the foundation for digital and green transformation. The SNS work program will serve as the foundation for calls for proposals that will be issued in early 2022. The SNS work programme is responsible for developing the first phase of the SNS roadmap and the expansion of the early wave of European 6G projects that were launched in January 2021 under the 5G-PPP. Figure 15 shows four main streams of the SNS programme. In terms of standards, we anticipate that projects funded under calls like ICT-52-2020 would contribute valuable insights to standardization bodies, assisting in developing advanced 6G systems and technologies. 3GPP believes that there are still features and capabilities from existing 5G systems that require full specification, which is planned to be delivered towards the end of 2023 according to the 3GPP schedule. To complete the transition from historical and existing proprietary radio protocols to 3GPP protocols, it will take around 5-10 years. The development of AI/ML-assisted privacy is still in its early stages. It will take time to respond to the new security and privacy threats presented by the dynamic nature of 6G services and networks.

IX. EMERGING AND FUTURE RESEARCH DIRECTIONS RELATED TO 6G PRIVACY

6G will cohabit with emerging technologies such as metaverse, quantum computing, cloud-native technologies, telco clouds, and Open RAN. We briefly describe these currently evolving, and upcoming technologies below that could potentially impact B5G/6G networks in the future.

1) Metaverse: The concept of metaverse initiated from the book named Snow Crash in 1992 [240], where it is regarded as a computer-generated virtual environment. There are characters in this environment, called “Avatars”, where they can perform actions similar to or even beyond the perception of the actual physical world. We see there will be a very high likelihood of becoming the metaverse mainstream since more people are inclined towards the remote working environment. Industrial attention on metaverse has significantly increased recently. For example, rebranding the name Meta for the Facebook company [241] emphasizes the plans on investing in metaverse by the private sector. The current work on metaverse will be accelerated by the introduction of B5G/6G communication since metaverse will need much higher data rates for communication. Especially important when considering high-quality three-dimensional environment rendering, multisensory remote devices, and the real-time connectivity of billions of users in a complex virtual environment to create a seamless social experience. There will be an array of new technologies with haptics to emulate sensations for metaverse users, demanding faster communication in B5G/6G, which may be crucial for their real-time operation.

The introduction of metaverse will clearly come with privacy concerns since they will be tracking user behaviour, PIIs, emotions, preferences in a three spatial dimensional virtual environment with complex multi-dimensional data that are not currently available, with new sensors and haptic technologies. Considering the behaviour of users, the work about a metaverse game named Second Life shows the majority of players (72% female and 68.8% male) show the same real-world result, which state that actual user behaviour can be traced by third parties which provide the metaverse. The critical factor here is that the user behaviour detected through indirect data analytics methods currently used will not be needed since the user may be virtually living spending most of their daily life in the metaverse. In metaverse VR/XR applications will be heavily used. The work in [6], for example, addresses how XR could acquire biometric data and physical motions. [82] also agrees that XR collects a diverse set of data. Since the sensing devices in these applications could track the user, which could be used to easily identify patterns of user behaviours, and the activity the user is doing. The possibility of privacy leakage would be much higher in such an environment since other private data such as user preferences and emotions could be easily predicted through the behaviours or actions. Also, as this information would be communicated through B5G/6G networks, there could be many privacy attacks since it is one approach to getting the user data in the metaverse.
2) Quantum Computing: Quantum computing is another emerging field related to B5G/6G privacy since the use of quantum computing operations would pose threats to the privacy of users since nearly all cryptographic schemes would likely become obsolete with the delivery of quantum computing [243]. For example, quantum computers can easily factor very large numbers, whereas classical computers do not. This forms the basis for asymmetric encryption, and thus it has many possibilities of decrypting the data, which could contain private data, leading to the leakage of privacy. These capabilities of quantum computers will be practical in the B5G/6G era in the upcoming decade; thus, special concern should be given to this since secure communication is a vital factor for privacy protection. It would also affect the privacy of IoT communication since these devices may also rely on lightweight cryptosystems due to their resource constraint environments [244]. However, quantum computing itself can act as the solution for the issues arising through it. The techniques such as quantum key-distribution use physics principles to encode and transmit data using photons, which is an unbreakable form of cryptography [243].

Not only prevent privacy leakages, but the use of quantum computing would also help enhance privacy, such as in ML operations. Quantum clustering is one such approach that can be used for privacy enhancement as discussed in [245]. It shows that fewer queries to the database will be required for clustering operations with quantum clustering algorithms, which would help reduce the possibility of privacy leakages. Such approaches for ML would benefit B5G/6G since the future networks, and their applications would heavily use ML.

3) Cloud Native Technologies: The cloud-native applications are built in the cloud, rather than the classical application development “on-premises”. The work in [246] provides a list of properties where cloud-native applications are different from conventional applications. It includes operation globally with replicated data, serving thousands of concurrent users by scaling well, assuming that infrastructure is fluid and failure is constant, and testing without disrupting the production. However, they show another characteristic that the cloud-native applications are made of aggregation of many different cloud components where they mention these components should not hold sensitive credentials. Also, they show the firewalls are insufficient as the access control need to be managed at multiple levels. Therefore, privacy should be a major concern for cloud-native applications. The designers of cloud-native applications could take privacy-by-design approaches, where privacy should be integrated with the application architecture. The work in [247] identifies issues in cloud-native system challenges and shows that software engineers are ill-equipped with privacy-preserving methods addressing all privacy principles and agile development of software engineering often neglect or even contradict privacy principles. There will be a further increase of cloud-native applications in the future with B5G/6G networks. Thus, novel privacy-aware development lifecycles should be investigated, and adoption techniques for privacy should be considered in software engineering practices.

4) Telco Clouds: The combination of the telecommunication sector with the cloud is an ongoing evolution by combining telcos with the clouds, mainly two ways [248]: 1) telcos supporting the cloud to provide scalable computing and storage services on demand, and 2) telcos using the cloud functions to implement virtualized service functions through hosting and cloud computing with NFV and SDN. It makes possible agile operation, adding services on demand, faster response to changes, and efficient management of resources. Therefore, we can expect Telco cloud operations will also be extensively used for B5G/6G networks due to their dynamic fulfillment of work.

The use of cloud technologies on network functions would also pose all privacy requirements associated with cloud infrastructure to the networks, such as a higher possibility of attacks since the traditional physical boundaries that define and protect information are transformed and disappear with the virtualization [249]. Therefore, future research work can focus more on telco cloud privacy protection mechanisms in the absence of these physical barriers, which would also help ensure privacy in general-purpose cloud computing and storage.

5) Open RAN: A Radio Access Network (RAN) is a vital component in mobile telecommunication systems that implements radio access technology. It is placed in between a remotely operated User Equipment (UE) and the core network and consists of physical infrastructure radio units such as base station antennas and processing units [250]. Open RAN is a concept where the RAN portion of the network is designed and built by combining hardware and software components from different vendors, using open and interoperable interfaces for multi-vendor implementation, commercial off-the-shelf hardware, and virtualization software [251], [252]. The O-RAN Alliance is the consortium defining the specifications of the Open RAN [251]. One of the key benefits of Open RAN is its capability of utilizing ML and AI to empower network intelligence through open and standardized interfaces [252]. Therefore, Open RAN will be a useful association for B5G/6G networks since these networks intend to operate in an intelligence-based control and management. It also provides flexible deployment options and service provisioning models of virtualized network elements in telco clouds [252].

However, we see there are certain privacy-related aspects here as well, since with the facilitation of AI and its possibility of having privacy attack scenarios as described in Section I. Also, the privacy issues such as the ability to identify UE by attackers unauthorized access are some other scenarios that pose potential privacy risks for users who get services through the Open RAN [253]. Therefore, to mitigate the issues, these risks due to evolving threats should be identified, and periodically re-assessed [253].

X. Conclusion

In this paper, we provide a comprehensive survey on the privacy aspects related to B5G/6G networks. Privacy is a subjective concept, which is differentiating based on numerous factors. Based on the taxonomies defined for privacy, we
define a set of goals that covers privacy aspects for the context of B5G/6G networks. However, several issues with varying difficulties are available to limit ensuring privacy. The addition of intelligence, ultra-high data rates transmitting both personal and non-personal data, and adopting a range of novel technology ecosystems with new sensing capabilities make future network privacy more challenging. Emerging research work, well-established concepts, and existing technologies in different fields can be used as potential solutions to cope with these challenges. We observe these solutions also have some gaps that need to be addressed, depending on various factors such as maturity, applicability, and costs of the solutions. We also discuss the lessons learned, their possible future directions, and other emerging topics that appear with B5G/6G networks to lay the foundation for further research to be made in the aspects of privacy.

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