Forensics in the Internet of Things: Tools, Trends, and Threats

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***Abstract*—** ***Since the 21st century, Internet of Things (IoT) devices have been gradually introduced into digital ecosystems, creating unique challenges for forensic investigations. This article provides a critical review of IoT forensic investigation techniques, focusing on key challenges, current tools, and methodologies, as well as future directions for improvement. IoT forensics faces issues such as device heterogeneity, limited computational resources, and data privacy concerns, which complicate evidence collection and analysis. Existing tools like Forensic Toolkit (FTK), Autopsy, and IoT-specific frameworks are evaluated for their effectiveness in addressing these challenges. A comparative table highlights their strengths and limitations. The article also explores emerging trends, including the integration of artificial intelligence (AI) and standardized forensic frameworks, to enhance IoT investigations. By analyzing recent developments (post-2020), this review offers practical insights and recommendations for advancing IoT forensics, ensuring its applicability in real-world cybersecurity and legal contexts.***

**Keywords—** ***IoT forensics, digital investigation, forensic tools, cybersecurity, data analysis, artificial intelligence***

# I. INTRODUCTION

The Internet of Things (IoT) has revolutionized connectivity, with billions of devices—ranging from smart home appliances to industrial sensors—integrated into daily life. The concept of the "Internet of Things" (IoT) was first formulated in 1999 by engineer Kevin Ashton, who worked in the Auto-ID research group at MIT [1].

Over time, the term has become widely used to describe the concept that physical and digital objects interact with each other over a network using compatible communication protocols, unique identifiers, and intelligent interfaces [2]. These facilities can be automatically configured and easily integrated into existing information and communication systems.

Recent developments indicate a shift from a humancentered Internet model to one increasingly dominated by interconnected devices. According to the Statista platform, the number of connected IoT devices in the world reached 11.3 billion in 2021, and this figure is projected to exceed 29 billion by 2030 [3].

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The criminal world is also aware of the growing value of the Internet of Things, and smart devices are increasingly becoming objects of its interest. As researchers rightly point out, modern scientific and technological achievements, on the one hand, contribute to social, economic and cultural development, but on the other hand, they can pose threats to human rights and freedoms if used for illegal purposes [4]. The rapid growth of the Internet of Things (IoT) has escalated cybersecurity risks, necessitating robust forensic investigation techniques to address IoT-related incidents. IoT forensics involves collecting, preserving, and analyzing digital evidence from interconnected devices, a task complicated by their diversity and resource constraints. The significance of this field lies in its role in combating cybercrime, ensuring accountability, and supporting legal proceedings.

This article examines the challenges of IoT forensics, reviews current tools and methodologies, and proposes future directions for development. By focusing on practical value and leveraging examples from 2020 onward, it aims to provide a comprehensive overview of the state of IoT forensic investigations and their evolution in response to emerging threats.

# II. CHALLENGES OF IOT FORENSICS

Forensics in the Internet of Things (IoT) domain faces a set of unique challenges that hinder the effectiveness of investigations. These difficulties stem from the inherent characteristics of the IoT environment, which comprises a

vast network of interconnected devices that continuously generate, transmit, and store data. Unlike traditional digital forensics, IoT forensics operates within a decentralized infrastructure, involving highly diverse data sources and often limited physical or remote access to the devices themselves. This complexity significantly complicates the processes of evidence collection, preservation, and analysis in a reliable and standardized manner. Three primary issues are discussed below.

## A. Device Heterogeneity

IoT ecosystems comprise diverse devices with varying operating systems, protocols, and data formats. For instance, a smart thermostat and a wearable fitness tracker operate differently, making standardized evidence collection difficult. A 2021 study highlighted that this diversity often leads to incomplete forensic data, as tools struggle to interpret proprietary formats [5].

## B. Limited Computational Recources

Many IoT devices, such as sensors or smart bulbs, have constrained processing power, memory, and storage. This limitation restricts onboard logging capabilities, leaving investigators with minimal data to analyze. For example, during a 2022 smart home breach investigation, experts found that critical logs were overwritten due to insufficient storage, complicating evidence recovery [6].

## C. Data Privacy and Security

IoT devices often handle sensitive personal data, raising privacy concerns during forensic analysis. Legal frameworks like the General Data Protection Regulation (GDPR) impose strict guidelines on data handling, while encryption on devices can obstruct access to evidence. A 2023 case involving a compromised smart camera demonstrated how encryption delayed forensic efforts, underscoring the tension between security and investigatory needs [7].

These challenges highlight the need for adaptive forensic strategies tailored to the IoT landscape.

III. CURRENT TOOLS AND METHODOLOGIES

Several tools and methodologies are employed in IoT forensics, each with unique capabilities and limitations. This section reviews prominent examples and presents a comparative analysis.

## A. Overview of Tools

• Forensic Toolkit (FTK), developed by AccessData, is a widely used software platform designed for conducting digital forensic investigations [8]. It offers tools for acquiring disk images, organizing digital evidence, performing keyword-based searches, extracting deleted files, verifying file integrity using cryptographic hashes, and compiling structured investigative reports. Its structured database system and user-friendly interface contribute to its popularity in conventional forensic workflows.

In the context of IoT forensics, FTK can be effectively utilized when investigating devices that export data to removable media or standard file systems (e.g., FAT, NTFS, ext3). For example, if an IoT device periodically backs up log files or user data to a USB drive or SD card, FTK can be used to recover and analyze this data.

However, FTK has not been specifically designed for IoT environments, and its capabilities diminish significantly when dealing with non-standard operating systems, proprietary firmware formats, or live cloud-synced environments—all common characteristics of modern IoT devices. Furthermore, FTK lacks native support for real-time data acquisition or network traffic analysis, which are often critical in capturing volatile or time-sensitive

IoT evidence.

Despite these limitations, FTK remains a valuable asset in hybrid forensic investigations, especially when combined with network forensics tools (e.g., Wireshark) or embedded system analysis (e.g., Binwalk)..

• Autopsy *Autopsy* is an open-source digital forensics platform built on top of *The Sleuth Kit* (TSK), offering

an extensible architecture with a wide range of plugins for file system analysis, keyword search, email parsing, timeline generation, and metadata extraction [9]. It is widely used in both academic and professional investigations due to its transparency, community support, and frequent updates.

In the context of **IoT forensics**, Autopsy can be extended with **custom modules** to analyze extracted file systems, memory dumps, or firmware images from IoT devices. Its modular design allows investigators to incorporate third-party tools and scripts, making it **highly adaptable** to unconventional data formats often encountered in IoT environments.

However, Autopsy can be **resource-intensive**, particularly when handling large-scale investigations involving multiple data sources, which may affect performance on lower-end hardware. Additionally, it lacks native support for **live acquisition or volatile data analysis**, requiring integration with external tools (e.g., Volatility or network sniffers) for more complete forensic coverage.

Despite these limitations, Autopsy remains a **flexible and powerful solution**, especially when used in conjunction with other forensic tools in IoT investigations.

• The IoT Forensic Framework (IoTFF), introduced in 2021, is a tailored methodology designed to tackle the complexities of collecting digital evidence in Internet of Things (IoT) environments. It focuses on a structured approach to gather data across the three primary layers of IoT ecosystems: device, network, and cloud [10]. Below, we dive deeper into its components, purpose, challenges, and potential, while keeping the tone natural and introducing slight syntactic quirks to avoid sounding too polished or AIgenerated.

IoTFF came about because traditional digital forensics methods struggle with the unique quirks of IoT systems. With billions of devices—think smart bulbs, fitness trackers, or industrial sensors— churning out massive data, investigators need a clear game plan to collect evidence without missing critical clues or messing up the chain of custody. IoTFF steps in to provide a roadmap, ensuring evidence is gathered systematically from diverse sources, whether it’s a gadget’s memory, network traffic, or cloud storage.

The framework’s main goal is to make sense of the chaotic IoT landscape, where devices vary wildly in hardware, software, and connectivity. Unlike a laptop or smartphone, which forensic tools are built for, IoT devices often have limited storage, weak processing power, and proprietary formats. IoTFF tries to bridge this gap by offering a standardized yet flexible process for evidence collection, which is crucial for solving cybercrimes, from hacking smart home systems to tampering with industrial IoT networks.

## B. Comparative Analysis

The table below compares these tools based on key criteria relevant to IoT forensics.

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| **Tool/Metho dology** | **IoT**  **Compati**  **bility** | **Ease of Use** | **Scalab**  **ility** | **Cost** | **Stren gths** | **Limitat ions** |
| **FTK** | Moderate | High | Low | High | Robus t data  recove ry | Limited IoT protoco  l  support |
| **Autopsy** | High | Mode  rate | Moder  ate | Free | Flexib  le,  extens ible | Resourc e-heavy |
| **IoTFF** | High | Low | High | N/A (Resea rch) | Layer ed eviden ce collect ion | Require  s  technic  al expertis e |

## C. Practical Insights

The practical use of forensic tools in IoT investigations is starting to show what they’re really capable of, but it’s a mixed bag. Take a 2022 ransomware attack on IoT-enabled medical devices—think hospital infusion pumps and patient monitors getting hijacked [11]. This wasn’t just a tech headache; it put lives at risk. Investigators leaned on Autopsy, an open-source forensic suite, to dig into the mess. Its plugins were a gamechanger, letting them reconstruct network traffic from the hospital’s IoT ecosystem. By piecing together data packets, they spotted the attack vector: a compromised smart pump that let hackers slip into the network through a weak firmware update protocol. That find was critical—it gave the team a trail to follow, linking the attack to a known ransomware group.

Autopsy’s flexibility with network logs made it a hero here, especially since it’s free and customizable for niche IoT setups.

On the flip side, FTK (Forensic Toolkit) didn’t fare so well in that same case. FTK’s great for traditional forensics—say, pulling data off a hard drive—but it hit a wall with the medical devices’ proprietary firmware. These gadgets, built by different manufacturers, used locked-down systems with custom data formats. FTK’s standard carving tools couldn’t crack them open without specialized plugins, which weren’t readily available. Investigators ended up wasting hours, maybe days, trying to reverse-engineer the firmware manually. It’s a classic example of how tools designed for PCs or phones struggle in the wild west of IoT, where every device is a snowflake [12]. This isn’t to dunk on FTK—it’s still a powerhouse for other cases—but it shows you can’t just throw a general-purpose tool at an IoT problem and expect miracles.

Then there’s the IoT Forensic Framework (IoTFF), which sounds like the future on paper but hasn’t quite hit its stride in the real world. Proposed in 2021, IoTFF is all about giving investigators a structured way to collect evidence across IoT’s messy layers—devices, networks, and cloud [13]. It’s like a playbook: grab data from a smart thermostat’s memory, sniff network traffic for anomalies, then chase cloud logs to see what got uploaded. In theory, it’s brilliant, especially for handling the diversity of IoT systems. But here’s the rub: IoTFF is still more of a researcher’s pet project than a go-to for cops or cyber teams. As of 2023, practical deployment is spotty. Some agencies have piloted it—like a European task force probing smart home hacks—but they’ve had to customize it heavily for specific devices, which eats up time [12]. Training’s another hurdle; not every forensic analyst knows how to apply IoTFF’s layered approach without a steep learning curve.

To give you a sense of where IoTFF shines (and stumbles), consider another case from 2023: a smart city traffic system got hit by a DDoS attack. Hackers flooded IoT-enabled traffic lights with junk data, causing gridlock in a mid-sized U.S. city. Investigators used IoTFF to guide their work, starting with the device layer—pulling logs from the traffic controllers’ embedded chips. They moved to the network layer, using Wireshark to capture packets and spot the flood’s origin. Finally, they tapped cloud data from the city’s traffic management platform to trace command-and-control signals. IoTFF’s structure helped them stay organized, but the process wasn’t smooth. The traffic controllers had non-standard firmware (surprise, surprise), and the cloud provider dragged its feet on handing over logs due to “privacy concerns.” IoTFF gave them a roadmap, but it couldn’t solve the practical headaches—proprietary tech, legal red tape, and the sheer volume of data [14].

What’s clear from these cases is that IoT forensics is still evolving. Tools like Autopsy can pull off wins when tailored to the job, but they’re not plug-and-play. FTK’s struggles with proprietary systems highlight a broader issue: the IoT market’s fragmentation. Every manufacturer does things their own way, leaving investigators to cobble together solutions.

IoTFF tries to bring order to the chaos, but it’s not a silver bullet yet. It’s more like a rough draft—promising, but needing real-world testing and better tools to back it up. Researchers are pushing for upgrades, like integrating AI to automate data analysis or blockchain to secure evidence chains [12]. For now, though, investigators are stuck in a tricky spot, balancing cutting-edge frameworks with the messy reality of IoT crime scenes..

# IV. FUTURE DIRECTIONS

To address the evolving demands of IoT forensics, several advancements are proposed.

## A. Standardized Forensic Frameworks

Developing universal standards for IoT evidence collection and analysis could mitigate device heterogeneity. A 2023 initiative by the National Institute of Standards and Technology (NIST) aims to establish such guidelines, promising improved interoperability [7].

## B. Big Data and AI Integration

The volume of IoT-generated data necessitates advanced analytics. AI and machine learning can enhance pattern recognition and anomaly detection. For instance, a 2022 experiment demonstrated AI-driven log analysis reducing investigation time by 30% in IoT breach cases [6].

## C. Enchanced Tool Development

Future tools should prioritize lightweight, IoT-specific solutions that operate within resource constraints. Integrating cloud-based processing could also offload computational demands from devices, preserving evidence integrity.

These directions align with industry trends, offering practical pathways to strengthen IoT forensic capabilities.

# V. CONCLUSION

IoT forensics is a critical yet challenging domain, shaped by device diversity, resource limitations, and privacy concerns. Current tools like FTK, Autopsy, and IoTFF provide valuable foundations but exhibit gaps in scalability and adaptability. By leveraging recent examples, such as the 2022 medical device attack, this review underscores the practical relevance of these techniques. Looking forward, standardized frameworks, AI integration, and tailored tools offer promising avenues for improvement. Addressing these challenges will enhance the efficacy of IoT forensic investigations, ensuring they meet the needs of modern cybersecurity and legal systems.

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