

Alternative Monitoring Approach for IPTV

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Abstract: IPTV emerged in the late 1990s as a solution for delivering Video on Demand (VoD) and live television over managed networks. Its widespread adoption accelerated after the expansion of broadband internet and the introduction of web technologies such as HTML5 and adaptive streaming protocols (MPEG-DASH and HLS), which enabled television content to be streamed directly through web browsers. Across Europe, major operators and platforms including Vivacom and A1 in Bulgaria, Zattoo, Molotov TV, Cosmote TV, and Waipu.tv have successfully adopted browser-based and OTT television services. The proposed solution is designed to collect IPTV viewership data while supporting remote device management. Its architecture includes a Chromium-based browser controlled through Selenium Wire, enabling the monitoring of network traffic and playback events. Additional components include a user management interface for collecting demographic information, utility tools for software deployment, inventory tracking and log processing, a secure data transmission module, and VPN-based remote administration. The study highlights a key challenge in IPTV audience measurement: The widespread use of end-to-end encryption, which limits traditional monitoring methods. Existing approaches typically rely either on cooperation with IPTV providers to access proprietary data or on computer-vision techniques that identify channels after the content has been decoded. Both approaches involve considerable technical, legal, and financial challenges. The proposed solution addresses these limitations by operating as a native IPTV client on standard consumer hardware. This enables the independent collection of multimedia metadata and playback information without bypassing the existing security mechanisms, thereby providing a provider-independent approach that can be evaluated for scalability in future work.

Keywords: IPTV, Streaming, Monitoring, People Metrics

Introduction

Internet Protocol Television (IPTV) is a technology for the transmission of television content via the Internet Protocol suite, serving as a sophisticated alternative to traditional distribution paradigms such as satellite, terrestrial, or cable broadcasting. One of the most streamlined and accessible options for consuming IPTV is through web browsers. This approach ensures cross-platform compatibility and provides users with a standardized, familiar interface.

This study analyzes methods for IPTV audience measurement and presents the design and implementation of a dedicated hardware and software prototype. The

system supports cross-device synchronization and remote management. The paper outlines the distinctive challenges associated with IPTV audience measurement, describes the hardware assembly and software architecture used for device control and viewership reporting, and presents contextual statistical data from the Bulgarian market.

The development of IPTV dates back to the late 1990s, emerging as a specialized solution for delivering Video on Demand (VoD) and live content over managed private networks. Following the rapid expansion of broadband infrastructure after the year 2000, these services achieved mass-market proliferation (Kim et al., 2020). The subsequent introduction of HTML5 and standardized

adaptive-bitrate streaming protocols, such as MPEG-DASH and HLS (HTTP Live Streaming), facilitated the direct delivery of television content through web browsers, eliminating the need for proprietary software or third-party plugins (Concolato and Le Feuvre, 2013).

The main factors contributing to the evolution of this media-distribution model are primarily socioeconomic and continue to gain importance. Key factors include:

- **Accessibility and Versatility:** Users can consume content from any internet-enabled device equipped with a web browser. Currently, this has become the *de facto* standard for all mobile devices
- **Personalization:** These platforms enable the provision of tailored content based on individual user interests and consumption patterns (Bonastre et al., 2011)
- **Mobility:** Browser-based IPTV facilitates ubiquitous access across a diverse range of hardware, including laptops, tablets and smartphones (Kim et al., 2012)
- **Interactivity:** Web-based platforms allow for the seamless integration of advanced features, such as multi-language support, subtitles, time-shifting (time-delayed viewing), and extensive content archives spanning several weeks (Klehm et al., 2022)
- **Cost Efficiency:** Distributing content via the internet significantly reduces operational and infrastructural expenditures compared to traditional terrestrial or satellite broadcast networks
- **Diverse Subscription Models:** These platforms offer a range of monetization strategies, including both free and premium tiers, with scalable options for supplementary features and enhanced functionality (Obele et al., 2009)

The central research problem addressed in this study is the reliable measurement of IPTV audiences in the presence of encrypted traffic and without direct access to provider-controlled data. The proposed approach employs an instrumented browser operating as a standard IPTV client to collect metadata, playback-state information, user-session data, and system telemetry. The principal contribution lies in integrating browser-based monitoring, hardware-level state detection, user registration, event logging, and cross-device synchronization into a unified, provider-independent system.

Literature Review

Browser-based IPTV (more precisely categorized as OTT/IP-based video services delivered via web environments) is extensively utilized by news media organizations, streaming services (e.g., Netflix, YouTube TV), and telecommunication operators. This implementation is part of a broader paradigm shift involving the transformation of traditional television and the transition toward Over-the-Top (OTT) delivery

models (Mulla, 2022). Its adoption is particularly prominent in regions with robust internet infrastructure and populations accustomed to streaming. Its proliferation is directly correlated with the quality of broadband connectivity, the penetration of smart devices, and the maturity of digital consumption patterns (Papathanasopoulos and Varoutas, 2026).

It can be argued that browser-based IPTV has become an established model for media consumption. OTT platforms are increasingly perceived as competitive and, in many instances, preferable alternatives to linear television (Menon, 2022). Owing to their advantages in accessibility, personalization, cost efficiency, interface usability, binge-watching support, and content availability, browser-based and OTT services are expected to continue gaining market share relative to traditional television distribution (Menon, 2022).

Of particular research interest are the opportunities for AI-driven personalized content generation and AI-based recommendation systems. These systems critically influence content discoverability, user satisfaction, and service retention (Gonçalves et al., 2024). Furthermore, integration with cloud distribution technologies facilitates the scalable delivery of video services over the internet. These advancements also enable targeted advertising within Advertising Video on Demand (AVoD) models, where personalized ad formats can increase engagement. However, consumer attitudes toward such advertising remain intrinsically linked to data privacy and control (Furini, 2023). Finally, hybrid monetization models combining subscription fees, advertising revenue, and micropayments have emerged (Li et al., 2024). It should be noted that contemporary literature more strongly supports subscription-based and ad-supported models over micropayments as the dominant mechanisms.

Specific examples of European operators providing such services are detailed below.

Current Market State

European Market

The following section outlines prominent European telecommunication operators and platforms that have successfully implemented browser-based and OTT service models:

- **Vivacom and A1 (Bulgaria):** These are the leading telecommunication service providers in Bulgaria, offering a diverse array of subscription-based television packages. Their flagship services EON (Vivacom) and Xplore TV (A1) are fully accessible via web browsers, ensuring seamless cross-platform availability
- **Zattoo (Switzerland/Germany):** Zattoo represents a premier television streaming platform, hosting over 200 public, private, and international channels.

Beyond its consumer-facing web and mobile applications, Zattoo provides comprehensive B2B solutions, enabling other telecommunication operators and media entities to deploy white-label, branded IPTV services

- Molotov TV (France): This French streaming entity utilizes a specialized interface to provide access to a wide spectrum of television networks. Molotov TV employs a hybrid monetization strategy, offering free tiers alongside premium subscriptions that include advanced technical features such as network personal video recorder (nPVR) and offline viewing capabilities
- Cosmote TV (Greece): Owned by the Hellenic Telecommunications Organization (OTE), Cosmote TV operates a converged model that integrates traditional satellite broadcasting with a robust OTT streaming platform. The service provides high-bandwidth content, including dedicated sports and cinematic programming, accessible through web environments
- Waipu.tv (Germany): A prominent German IPTV provider, Waipu.tv specializes in the delivery of linear television and Video on Demand (VoD). The platform distinguishes itself through flexible subscription architectures that support both high-definition live streaming and integrated cloud-based recording functionalities

Bulgarian Market Distribution and Trends

To contextualize the shift toward IP-based technologies, current market distribution metrics are presented. Recent data from 2025 illustrate the competitive landscape of television signal reception. As shown in Table 1, IPTV has emerged as the leading distribution platform, surpassing traditional methods such as Direct-to-Home (DTH) satellite and digital cable. This trend underscores the transition of the consumer base toward infrastructure that supports the browser-based and OTT models discussed previously.

The data indicate that IPTV accounts for a substantial share of the examined segment of the Bulgarian market and support the need for complementary audience-measurement methods. These findings are used solely to contextualize the present study and should not be interpreted as a universal projection for all European IPTV and OTT markets.

System Setup

The current methodologies for IPTV monitoring necessitate specialized software concepts and architectural frameworks that are meticulously adapted to both hardware constraints and the unique characteristics of IPTV network traffic. This requirement is exemplified by the GPM3 approach, which provides a comprehensive solution for monitoring IPTV devices. This framework encompasses the systematic planning, development, and implementation of monitoring software for IPTV clients used by major providers such as A1 and Vivacom, as detailed in Hristov et al. (2022).

Given the established presence and continued growth of the IPTV segment, it is imperative to address the collection and processing of viewership metrics. The software discussed here represents an end-to-end solution specifically engineered for monitoring web-based media content. This category includes not only the aforementioned IPTV technologies but also OTT services such as YouTube and Netflix. Some OTT platforms, including YouTube, provide public APIs that may support the development of dedicated integration modules. Through the development of appropriate integration modules, the proposed software could be adapted to collect selected viewership-related metrics from compatible platforms.

The application is deployed on the Armbian OS (v24.8.3 Noble), utilizing the NanoPi R6S hardware platform. The NanoPi R6S is a high-performance gateway featuring dual 2.5G Ethernet ports and a powerful Rockchip RK3588S SoC, making it suitable for high-throughput traffic analysis.

The system architecture comprises the following key components:

Hardware and Architectural Modules

The system integrates a suite of specialized modules designed to monitor the operational status of the television set (Power On/Off states). These modules provide a multi-modal approach to status detection, utilizing the following methodologies:

- Status Monitoring Subsystem: This component employs several alternative techniques for state detection:

Table 1: Comparative analysis of TV signal reception in Bulgarian market in 2025

Signal type	Household count	GARB panel %	Real market share %
Terrestrial	33	3.3%	3.1%
Cable Digital	225	22.8%	23.9%
DTH (Satellite)	344	34.9%	35.4%
IPTV	378	38.3%	36.7%
Other	6	0.6%	0.9%

- Smart Socket Integration: Utilizing network-connected power outlets for remote state sensing
- Power Consumption Analytics: A dedicated module that measures the electrical current draw of the television receiver to determine active usage
- HDMI-CEC Protocol Monitoring: Leveraging the Consumer Electronics Control (CEC) standard over HDMI to track hardware power states and inter-device signaling
- USB Serial Controller Interface: Implementing serial communication to ensure continuous TV monitoring

This multi-layered monitoring aligns with established industry practices regarding the use of browser logs as primary outputs for observing web applications during automated monitoring processes:

- Remote Control Module: An input management system based on AirMouse technology, facilitating navigation
- User Interface (UI) Abstraction Layer: Beyond standard remote controls, this module integrates keyboard and mouse inputs, providing an additional level of abstraction from specific hardware devices and enhancing system flexibility
- Cross-Device Synchronization Module: A specialized component designed to synchronize user profiles and states across multiple devices within a single household, ensuring data consistency
- Telemetry and Logging Engine: This module is responsible for the generation of structured log files, which are critical for subsequent viewership analysis and user behavior modeling. This architecture supports the implementation of AI and Big Data analytics within video streaming platforms to optimize content delivery and enhance the overall user experience (Arshad et al., 2025)

Software Architecture

The software is engineered to facilitate high-fidelity data ingestion and remote management through the following core components:

- Instrumented Web Browser Engine: The system utilizes a programmatically controlled web browser based on the Chromium engine, interfaced via the Selenium Wire driver. This specialized approach to instrumented IPTV monitoring enables the interception of request/response headers and traffic analysis, as documented extensively in the GPM3 framework (Hristov et al., 2023)
- Integrated User Management Interface: A supplementary UI component manages the registration and authentication of primary users and guests. This module is seamlessly integrated into the

provider's native IPTV web interface, ensuring a unified user experience while capturing granular demographic data

- System Utility Suite: A set of auxiliary programs handling lifecycle management and data pipeline operations, including:
 - Deployment and Maintenance: Tools for automated initial installation and software updates
 - Inventory Management: Automated tracking of hardware and software configurations
 - Log Aggregation and Transformation: Utilities that compile raw telemetry into standardized formats optimized for downstream analytical processing
- Data Transmission Engine: A specialized module for the secure transmission of aggregated metrics to a centralized analytics server

Secure Remote Access Infrastructure: The implementation of a persistent Virtual Private Network (VPN) ensures a continuous management plane. This allows network operators to perform real-time monitoring, troubleshooting, and remote configuration of the device regardless of its physical network location.

The system architecture facilitates a controlled environment where user interaction is mediated through a remote control unit (and optionally via mouse and keyboard peripherals). These interactions, comprising button presses, keyboard events, and navigational inputs, are captured as User Interaction (UI) logs. These logs record low-level activities within the system, including clicks and the occurrence of text-input events, without recording the entered textual content.

To ensure system integrity, direct access to the underlying operating system is restricted. All commands and data inputs must transition through the application's control interface. The operational lifecycle is defined as follows:

- System Activation: Upon engaging the "Power" command via the remote control, the application initializes the primary Graphical User Interface (GUI). This interface serves as the entry point for system interaction, safely mapping user inputs to commands that modify the system state (Blouin and Jézéquel, 2022)
- Session Management: A modal registration window is presented for user or guest registration. This component is an integral part of the UI abstraction layer
- Browser Initialization: Following successful authentication, the instrumented browser engine is launched, automatically navigating to the last accessed channel

- **State Persistence:** The system dynamically updates a local configuration file during channel transitions to ensure the last active state is preserved for subsequent sessions
- **Real-time Interaction Processing:** The system polls for user inputs (e.g., keystrokes, mouse clicks) several times per second. This ensures low-latency responsiveness, effectively linking physical interactions with programmatic actions. Such lightweight tracking of clicks and keyboard inputs is a recognized method for enhancing usability analysis in web-based environments (Jiang and Feng, 2025)
- **Optimized Command Mapping:** Intercepted actions are mapped to a predefined set of control functions such as channel selection, playback pause, and time-shifting. This design follows established UI principles aimed at making interaction efficient and user-friendly by minimizing the input effort required to achieve desired multimedia control outcomes

System Implementation

The integration of user registration and multimedia control into a unified hardware interface necessitates strict

state management and synchronization protocols. The following section details the governance of user sessions and the distributed synchronization mechanism. The registration of users and the control of multimedia playback are consolidated within a single remote control interface. Its functions are programmable to allow for hardware flexibility. To ensure the integrity of the monitoring environment, a walled garden approach is implemented. Network access is strictly confined to the IPTV provider's domains, with all other external web traffic prohibited.

Application Operational Workflow (Initialization, Interaction, and Termination)

The overall interaction between the core system components is shown in Fig. 1. Input events generated by the remote control, mouse, and keyboard are processed by the browser application, which manages multimedia playback and user registration. In parallel, Selenium Wire monitors network requests, the TV status monitor determines the operational state of the television receiver, and the logging component consolidates the captured events into structured records.

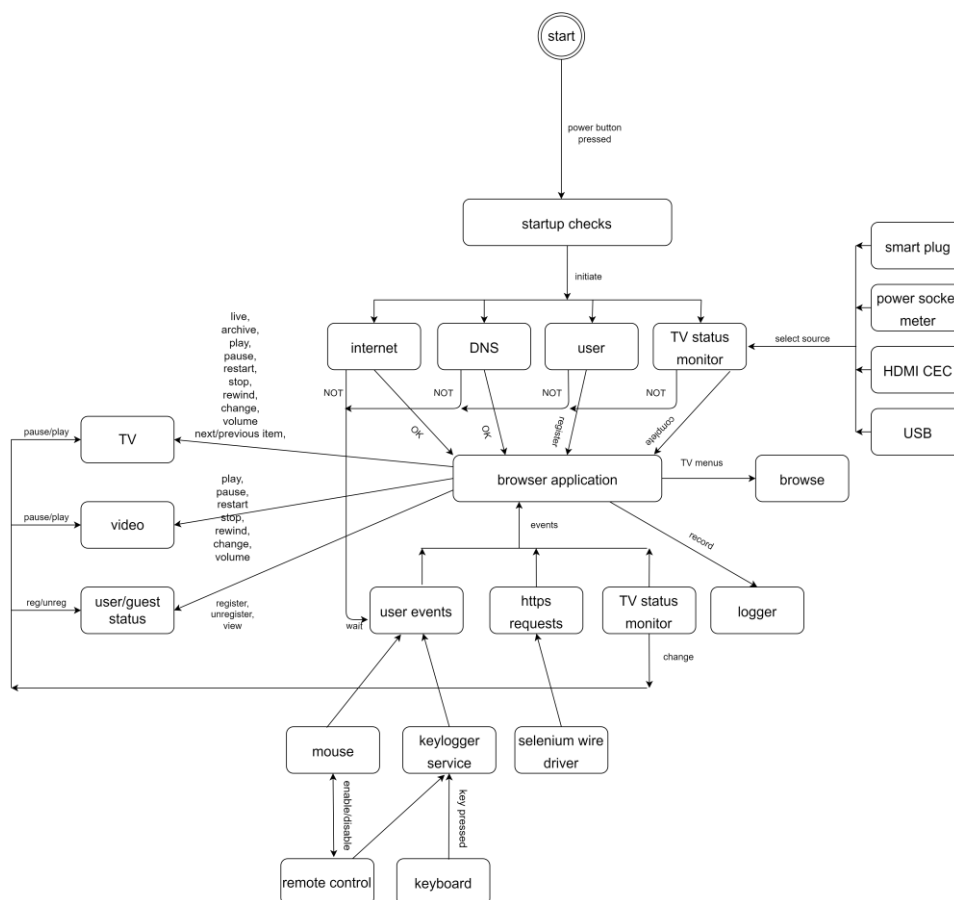


Fig. 1: Interaction diagram of core system components

The synchronization module exchanges user-session state information among the monitoring devices connected to the local network. The system maintains a persistent, interactive user registry that can be invoked at any time via either the remote control or mouse input. This interface allows for the dynamic addition or removal of users and guests. Crucially, the system architecture enforces a mandatory active session state. The application does not permit a state where no users or guests are registered. In such instances, the registration menu is forcibly rendered as a modal overlay until a valid session is initiated.

A critical feature of the proposed system is the automated synchronization of user/guest sessions across multiple devices within a single household. To maintain the validity of viewership data, the system must prevent a single user from being simultaneously registered on multiple monitoring devices. To mitigate the risk of redundant monitoring, a synchronization module was developed based on IP Multicast communication. The protocol operates as follows:

- **State Propagation:** When a change occurs in the local registration state (e.g., a new user registers), the device broadcasts a state-change message to the local network segment
- **Conflict Resolution:** All other active devices on the network receive this multicast message. If a device detects that its currently registered user has signed in on a different hardware unit, it automatically terminates the local session and purges the registration data
- **Uniqueness Constraint:** The mechanism is designed to maintain a one-to-one association between a user and an active monitoring device, thereby reducing the risk of duplicate registration. A temporary loss of a multicast message may result in a short-lived inconsistency between device states. This risk can be mitigated through periodic state updates, timestamp-based validation, and the rejection of stale or duplicate messages. More extensive testing under packet-loss conditions and in the presence of invalid state-change messages remains part of the planned future validation

The system architecture includes a power-management lifecycle that synchronizes the application state with the hardware status of the television receiver. This ensures both computational efficiency and data integrity during periods of inactivity. The operational transitions are defined as follows:

- **Deactivation Sequence:** Upon detection of a "Power Off" signal, either from the television hardware via HDMI-CEC or power-consumption monitoring, or from a manual "Power" command issued through the

remote control, the system executes the following shutdown routine:

- **Playback Suspension:** The active IPTV stream is immediately paused to cease data consumption
 - **Interface Minimization:** The graphical application is moved to a background state
 - **Session Termination:** All active user and guest registrations are purged to ensure a clean state for the next session
 - **Resource Optimization:** In this dormant state, the application suspends active playback and reduces background activity, preserving the hardware resources of the NanoPi R6S
- **Reactivation and Recovery:** When a "Power On" event is triggered, the system demonstrates high responsiveness, achieving full functional restoration within a 2–3 second latency window. The restoration sequence follows a deterministic order:
 1. **UI Maximization:** The application interface is restored to a full-screen state
 2. **Stream Resumption:** The previously active channel is re-initialized as a live stream
 3. **Registration Prompt:** The user/guest registration modal is immediately rendered, requiring a valid session before further interaction is permitted

Data Logging Methodology and Standardization

The system implements a continuous data ingestion strategy to ensure a comprehensive record of user activity. Telemetry is captured at a high temporal resolution, with a new data entry appended to the viewership log every 2–3 seconds. To maintain a contiguous 24-hour monitoring period, the system generates automated "null-state" administrative records during intervals of inactivity. All data is structured in Comma-Separated Values (CSV) format to facilitate interoperability and downstream analysis.

The architecture of this logging mechanism addresses a significant gap identified in contemporary research. Dubovskis et al. (2015) note that there is no unified standard for collecting and processing IPTV statistical data, that vendors handle such data differently, and that some solutions do not allow the collection of data about watched television channels and programs.

To overcome these vendor-specific limitations, this approach utilizes an automated browser capable of capturing both application-level events and console telemetry. While this methodology provides superior visibility into web-based media delivery, it operates beyond the native capabilities of standard automation frameworks. As noted in recent literature: "Log gathering is not part of the standard mechanism for browser

automation... there is no cross-browser mechanism widely adopted to date for performing this task in automated tests." (García et al., 2023).

By integrating the Selenium Wire driver (as detailed in the software setup), this system successfully implements a non-standard monitoring layer that intercepts network-level data and browser console outputs. This ensures that even in the absence of a unified industry standard, the monitoring solution remains vendor-agnostic. The telemetry generated by the monitoring system is structured into a standardized schema within the CSV files. Each record appended to the viewership log comprises the following fields:

- Temporal Metadata: The current date and timestamp of the observation
- Channel Identifier: The specific name or ID of the television channel being accessed
- Playback State: The current operational mode of the media stream (e.g., Live, Time-shifted, or Paused)
- Program Timeline (Optional): A conditional field populated exclusively for non-live content, indicating the specific time offset of the archived program
- Demographic Data: A comprehensive list of the specific users and guests currently registered in the active session
- TV Hardware State: The operational status of the television receiver as detected by the hardware monitoring modules (Power On/Off)

To support efficient data management and future scalability evaluation, the local viewership log undergoes a daily aggregation and normalization process. During this phase, raw entries are summarized and converted into a unified interchange format for transmission to the centralized server and subsequent statistical processing and cross-device analysis.

Null-state records denote periods in which no active user session is present and are classified separately during the daily aggregation process so that they are excluded from active-audience calculations. The system processes predefined control events and structured data fields. Input values and CSV records are validated against the expected data types and formats prior to centralized processing, while free-text content and unnecessary sensitive information are excluded from the logs.

Results and Discussion

Prototype Observations and Scope of Validation

During prototype operation, full system functionality is restored within 2–3 seconds after activation, while telemetry records are generated at intervals of 2–3 seconds. These values characterize the observed behavior of the evaluated prototype configuration but do not

constitute a comprehensive performance benchmark. CPU utilization, memory overhead, long-term reliability, and system behavior under large-scale multi-device deployment were not systematically evaluated in the present study.

Practical Advantages and Limitations

The proposed approach does not require direct access to IPTV providers' databases and does not rely on graphical recognition of decoded video content. Its principal limitations arise from its dependence on the browser environment, potential changes to IPTV platform interfaces, and the requirement for a locally deployed hardware device. Accordingly, the reported results should be interpreted as validation of the architectural concept and the operational prototype rather than as evidence of scalability beyond the evaluated prototype configuration.

Security, Privacy and Data Protection Considerations

The proposed system incorporates core data-protection principles, including data minimization, pseudonymization of user identifiers, restricted administrative access, and protected transmission of aggregated telemetry. Only information required for audience measurement is retained, while free-text content and unnecessary sensitive data are excluded from the logs. Input values and CSV records are validated prior to centralized processing, and remote administrative access is restricted to authorized personnel through the VPN infrastructure. A comprehensive security audit, a formal GDPR compliance assessment, and a detailed data-retention policy remain subjects for future work.

Limitations and Future Work

Potential future work includes systematic measurements of CPU utilization and memory overhead, long-term reliability and scalability testing, validation across a broader range of IPTV and OTT platforms, and further evaluation of system behavior under network-failure conditions. The modular architecture supports adaptation through modifications to the integration modules; however, the continuing evolution of browser APIs and provider-specific security mechanisms may necessitate subsequent system updates. International validation, predictive analytics, and formal modeling of the synchronization mechanism are regarded as longer-term research directions.

Conclusion

This study presented an alternative approach for IPTV audience measurement based on a browser-driven monitoring device that operates as a functionally equivalent IPTV client. The proposed architecture enables

the collection of viewership-related metadata, playback events, user-session information, and system telemetry without requiring direct access to encrypted multimedia streams or proprietary provider databases. In this way, the approach addresses a key limitation of traditional IPTV monitoring methods, which commonly depend either on cooperation with service providers or on post-decoding visual recognition techniques. The main contribution of the proposed solution is the integration of hardware status monitoring, user registration, browser instrumentation, event logging, remote management, and cross-device synchronization into a unified monitoring workflow. This makes it possible to collect structured IPTV usage data in a provider-independent manner while preserving the security mechanisms of the original IPTV delivery environment. The proposed methodology is particularly relevant in markets where IPTV and OTT-based television services are becoming dominant forms of media consumption. Future work should focus on extended field validation, long-term reliability testing, integration with additional IPTV and OTT platforms, and further standardization of the collected telemetry for large-scale audience measurement and statistical analysis. Longer-term research directions include international validation, predictive analytics, and formal modeling of the synchronization mechanism.

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Author's Contributions

Angel Ignatov: Contributed to the conceptualization of the study, system architecture, software implementation, hardware integration, data collection, and preparation of the initial manuscript draft.

Hristo Toshkov Hristov: Contributed to the conceptualization and methodology of the study, supervision of the research process, validation of the proposed approach, project coordination, and manuscript review and edited.

Jan Latal: Contributed to the methodological refinement of the study, technical validation of the proposed architecture, interpretation of the results, and manuscript review and edited.

Ivan Ivanov: Contributed to the software implementation, system testing, hardware and network configuration, data logging procedures, and technical validation of the monitoring workflow.

Simeon Kondov: Contributed to the implementation support, experimental testing, data processing, analysis of system behavior, and manuscript review. All authors have read and approved the final manuscript.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

Conflict of Interest

The authors declare that they have no conflict of interest.

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