Establishing Trust in Online Advertising with Signed Transactions

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Abstract—Programmatic advertising operates one of the most sophisticated and efficient service platforms on the Internet. However, the complexity of this ecosystem is the main cause of one of the most important problems in online advertising, the lack of transparency. This lack of transparency leads to subsequent problems such as advertising fraud, which causes billions of dollars in losses.

In this paper we propose Ads.chain, a technological solution to the lack-of-transparency problem in programmatic advertising. Ads.chain extends the current effort of the IAB in providing traceability in online advertising through the Ads.txt and Ads.cert solutions, addressing the limitations of these techniques. Ads.chain is a communication protocol that provides end-to-end cryptographic traceability at the ad transaction level. It can be seamlessly embedded in ad-tags and the OpenRTB protocol, the de-facto standards for communications in online advertising, allowing an incremental adoption by the industry.

We have implemented the protocol and made the code publicly available. We assess the performance of Ads.chain through a thorough analysis in a lab environment that emulates a real ad delivery process. The obtained results show that our protocol adds delays lower than 0.25 ms per ad space on the web page and a marginal delay of 0.8 ms on the intermediaries. These results confirm its impact on the user experience and the overall operation of the programmatic ad delivery process can be considered negligible.

I. INTRODUCTION

Online advertising is a multi-billion dollar business. The Internet Advertising Bureau (IAB) reported that the revenue generated by online advertising was $107B in 2018, with an inter-annual growth rate over 16% [1] in the first semester of 2019. Besides, online advertising is the main source of revenue of some of the most important Internet companies, such as Facebook [2] or Google [3], which are fundamental contributors to the Internet innovation.

Programmatic advertising operates one of the most sophisticated and efficient service platforms on the Internet, which allows to deliver tailored ads based on tens of parameters (e.g., interests and online behavior of users, the context of the website/mobile app) through a real-time auction process. The overall process occurs in the order of hundreds of milliseconds and runs on top of a very complex ecosystem depicted in Figure 1. In particular, the process of delivering an ad from an advertiser to a website or mobile app involves several players, such as Demand-Side Platforms, Ad Exchanges, Supply-Side Platforms, and Ad Networks. The revenue generated by the impression of the advertiser’s ad is then split between the website and the involved intermediaries.

The complexity of this ecosystem is the main cause of one of the most important problems in online advertising, the lack of transparency. This lack of transparency leads to subsequent problems such as advertising fraud—which attracts between 5% and 19% of the overall online advertising revenue [4], [5]—or misreporting of ad campaigns information to advertisers [6], [7]. The online advertising industry has reacted to the accusation of lack of transparency creating auditing companies referred to as verifiers. However, in practice, these verifiers also use opaque auditing techniques that do not help to solve the problem [8], [7], [4], [5].

In this paper we propose Ads.chain, a technological solution to the lack-of-transparency problem. In particular, we define a communication protocol to provide end-to-end cryptographic traceability at the ad transaction level. In Ads.chain, every intermediary involved in the delivery process of an ad has to include a digital signature in the messages passed to its buy-side partner. The signature certifies the integrity and non-repudiability of the parameters containing relevant information. Therefore, each ad transaction produces a chain of digital signatures including the identity of each of the involved intermediaries and their actions. These chains of signatures provide guarantees of full transparency since any illegal or inappropriate action, as well as its perpetrator, can be identified by auditing the chains. Besides, the design of the protocol as a chain of signatures allows an incremental adoption by the industry.

Ads.chain can be seamlessly embedded in ad-tags and the OpenRTB protocol, the de-facto standards for communications between intermediaries in the online advertising ecosystem. Moreover, it leverages the existing Public Key Infrastructure (PKI) used for HTTPS communications to generate digital signatures. Hence, the protocol is readily implementable in the current ecosystem without requiring any modification, lowering the entry barrier for its adoption significantly. We

*For clarity, we will refer only to websites where websites and mobile apps are equivalent. Differences will be contemplated explicitly.
have implemented the protocol and made the code available through the following GitHub repositories [9], [10]. We assess the performance of Ads.chain through a thorough analysis in a lab environment that emulates a real ad delivery process. The obtained results show that our protocol adds delays lower than 0.25 ms per ad space on the web page and a marginal delay of 0.8 ms on the intermediaries. These results confirm its impact on the user experience and the overall operation of the programmatic ad delivery process can be considered negligible.

The rest of the paper is organized as follows. Section II describes the operation of the programmatic online advertising ecosystem. Section III introduces Ads.chain, our proposed protocol to provide end-to-end traceability to individual ad transactions in the online advertising ecosystem. Section IV details the implementation of the proposed protocol and the lab environment in which we test its performance as described in Section V. Finally, Section VI concludes the paper.

II. BACKGROUND

In this section, we provide an overview of the operation of the online advertising ecosystem and relevant details of ad-tag calls and OpenRTB messages, where our traceability protocol will be embedded. Moreover, we summarize some of the proven consequences of the lack of transparency and discuss some of the proposals from the industry that partially address this issue.

A. Online Advertising Overview

In its inception, online advertising mimicked the scheme used in traditional media advertising, where advertisers and publishers (i.e., owners of websites and mobile apps) closed deals to show advertisers’ ads into a publisher’s websites through either a direct agreement or involving just one intermediary. In recent years, the model has rapidly evolved to the known as programmatic advertising ecosystem where ads are traded through a complex and heterogeneous set of automated platforms, often individually and in real-time. These platforms communicate among them in order to serve a suitable ad for a predefined ad space on a web page (or mobile app).

The messaging mechanisms and protocols these entities use to communicate with each other are fairly standardized and described later in this section.

1) Programmatic Advertising Operation: When a user visits a website, the HTML document of the page is requested from the web server of publisher.com. This HTML document contains an ad-tag for every ad space the publisher allocates on the page. Ad-tag is the term used for the HTML code snippets containing the URLs to retrieve ad-related content [11]. Each ad-tag contains a URL pointing to the publisher’s ad server to which the user’s browser performs an HTTP request starting the ad serving process. The URL of the ad-tag contains information about the ad space.

Upon the reception of a request from the user’s browser, the publisher’s ad server may enrich the request with information about the user profile using proprietary information or requesting it to a Data Management Platform (DMP),2 if the ad server finds a pre-configured ad campaign suitable for the user’s profile, the user’s browser retrieves the pre-configured ad from the advertiser’s ad server. These pre-configured campaigns typically correspond to private deals between advertisers and publishers. In case there are no current pre-configured campaigns for the user’s profile, the ad server forwards the ad request to a Sell-Side Platform (SSP) or ad network. These traders try to sell the ad space through private exchanges where only a selected group of buyers have access to.

If the ad request is still not sold through these private channels, the publisher’s ad server will place the ad request in the open market. This process is usually done through an SSP that will forward the ad request to an Ad Exchange (AdX) [12]. The AdX launches a real-time open auction. To this end, it sends a bid request message to Demand-Side Platforms (DSPs). This bid request message includes information about the ad space (e.g., type, size, and location in the web page), the domain (i.e., the website or mobile app), and the user’s profile and device. The DSPs are entities where the advertisers’ ad campaigns are pre-configured. Upon the reception of the bid request, a DSP checks whether the parameters included in the bid request match any of the pre-configured campaigns. If so, they respond to the bid request with a bid response that includes the bidding price as well as the ad-tag pointing to the URL of the ad. Note that the ad can be hosted in either the advertiser’s or the DSP’s ad server. Upon the reception of the bid responses from different DSPs, the AdX runs an auction. The AdX informs the winning and losing DSPs with win and loss notice messages, respectively. Moreover, the URL for retrieving the ad is forwarded following the inverse chain of communication from the AdX to the user’s browser. The advertiser’s (or DSP’s ad server) receives the URL request from the user’s browser, and then it accounts the impression as performed.

Figure 1 graphically depicts the process described above. Note that the overall described process takes in practice less

2Note that DMPs can be queried from any other intermediary entity in the ad delivery process.
than a second, from which the auction process is restricted to less than 300 ms in most AdX\(^4\).

2) Message Formats and Communication Protocols: The complex procedure described above relies on the exchange of different types of messages. We can differentiate two clear parts in the overall programmatic process. On the one hand, the sell-side involves all entities participating in the process until the communication reaches the AdX: the publisher, the publisher’s ad server, and the SSP. On the other hand, the buy-side is formed by the DSPs. Finally, the AdX is the entity communicating the sell and buy sides.

The communication between AdXs and DSPs in the buy-side uses the Open Real-Time Bidding (OpenRTB) protocol, which is a standard defined by the IAB and adopted by the industry. The OpenRTB defines the format and order of messages exchanged between AdXs and DSPs (bid request, bid response, win/loss notice, and billing notice). OpenRTB uses HTTP as the communication protocol and JSON (JavaScript Object Notation) format for data serialization. The latest operational version is v3.0. It was released in November 2018 and includes a beta version of Ads.cert, a mechanism to provide signed bid requests, which is one of the basic components we leverage in our solution to create an end-to-end chain of signatures per ad transaction.

The sell-side entities rely on ad-tags as mean to communicate with each other. The response to an ad-tag can be another ad-tag or the final advertisement. The structure of an ad-tag may vary depending on its function. They may include JavaScript code to perform dynamic tasks at rendering time or even a no script section for the browsers with JavaScript disabled. The information about the ad impression—such as iframe size, user’s profile, or the winning price—is embedded in the URL’s query string, the URL part after the question mark symbol (\(^?\)). The parameters in the query string are in the format of key-value pairs using an ampersand symbol (\(\&\)) to separate parameter pairs and an equal sign (=) between the keys and their respective values. Figure 2 shows an example of an ad-tag.

![Fig. 2. Example of an ad-tag defining an ad space on a web page.](image)

**B. Lack of transparency and the fraud problem**

The online advertising industry has managed to develop a very efficient ecosystem able to deliver tailored ads involving a real-time auction process in a few hundreds of milliseconds. However, this technology development lacks appropriate, objective, and transparent auditing mechanisms. There is no way to check the validity or veracity of the parameters that an entity A passes to an entity B (through ad-tags or OpenRTB messages). Moreover, advertisers are left out of the process, and what they receive are processed reports summarizing the performance of their campaigns, which has been reported to be inaccurate [6]. Besides, this lack of transparency is the fundamental cause of ad fraud, one of the most important problems of online advertising. There are different reported forms of ad fraud: from basic attacks using bots to visit websites where ads are shown [13], [6] and even clicked [14], to more sophisticated attacks using malicious software—referred to as adware—that performs hidden visits to websites from a user’s browser [15].

Pushed by advertisers’ concerns about the lack of transparency, several independent companies have appeared in the last years referred to as verifiers: e.g., IAS [16], Withe Ops [17], DoubleVerify [18]. These companies use ad-tags embedded in publishers’ websites, containers of ads such as iFrames, or the ad creativity to monitor the delivery process of individual ad impressions. However, these companies operate in an opaque manner. They use proprietary technology which has not been validated. Indeed, the effectiveness of their technology has been questioned by research studies [8], [7] suggesting that solving the fraud problem using opaque auditing techniques is not an appropriate approach.

Given the lack of transparency, the fraud problem is not isolated to artificial traffic to untrustworthy publishers. Recent reports document high scale cases of counterfeit inventory fraud. In this type of attack, fraudsters take advantage of the impossibility to validate the veracity of the information included in ad-tags or OpenRTB messages. Domain spoofing is a well-known attack to introduce counterfeit inventory in the programmatic ecosystem [19]. In particular, fraudsters launch fraudulent ad requests from instrumented browsers claiming they came from popular domains, referred to as premium sites, where ad spaces are more expensive. The IAB Tech Lab has proposed specific ad-hoc solutions to this alarming problem: Ads.txt and Ads.cert.

The Authorized Digital Sellers Ads.txt specification, launched in 2017, consists of a plain text file where publishers publicly declare which are the traders (e.g., ad networks, SSPs, and exchanges) they operate with. Hence, any player can check whether the ad request comes from a valid trader. This ad-hoc solution has obvious limitations: publishers not adopting it and implies a blind trust in authorized sellers [20] and authorized resellers that could have received the requests through an unauthorized source [19]. Given the limitations of Ads.txt, the IAB launched the Ads.cert specification, whose beta version is included in OpenRTB 3.0. Ads.cert defines a standardized mechanism by which the publishers can sign the ad requests using public-key cryptography to provide proof of their identity. Although this step goes in the right direction to address the counterfeit inventory, it is not an end-to-end solution to provide full transparency to ad transactions and has limitations as recognized by the IAB in Section 6 of the same specification\(^4\). For instance, the current definition of Ads.cert introduces a new vulnerability: it allows a malevolent platform in the selling chain to replicate signed ad requests originated

\(^4\)https://github.com/InteractiveAdvertisingBureau/openrtb/blob/master/ads.cert-%20Signed%20Bid%20Requests%201.0%20BETA.md

\(^5\)https://developers.google.com/authorized-buyers/rtb/start

6-limitations-and-abuse-vectors-
at a compromised user’s browser. The replicated ads can be sold to different buyers or even to the same DSP if appropriate sanity checks in the received inventory are not performed.

Extending these initial efforts by the IAB, we define Ads.chain, an end-to-end solution that enables full traceability of each individual ad transaction. Our protocol provides a more dynamic solution than Ads.txt to mitigate the possibility of introducing counterfeit inventory and extends the signatures defined in Ads.cert to the complete chain of custody of each ad transaction to avoid vulnerabilities, such as the replication of ad requests.

III. Ads.chain PROTOCOL DESIGN

In this section we describe in detail Ads.chain. We start identifying the requirements the protocol has to meet to achieve its purpose (end-to-end traceability of ad transactions) while being implementable in the current programmatic ecosystem. Then, we describe the protocol, and finally, we describe how to seamlessly integrate it into the current online advertising ecosystem.

A. Protocol Requirements

- **Unequivocal custody**: In an ad delivery process, only one player has the right to re-sell the ad space at a time, following the scheme described in Figure 1. In other words, only one player has the custody of the ad at a given moment. In the current ecosystem, a malicious player may declare to own the custody of an ad space, and there is not an easy way to prove if it is true or false. Hence, the defined protocol must guarantee the unequivocal custody principle by which it will be verifiable if a player owns the custody of an ad.
- **Non-repudiability**: any action taken by a player can be undeniable. This property is referred to as non-repudiability in the security discipline.
- **Low latency**: the overall ad delivery process takes hundreds of milliseconds in programmatic advertising. Therefore, the protocol must incur delays in the order of a few ms to have a minimal impact on the overall delivery process. On the other hand, the impact on the overall page loading time should be likewise small to avoid affecting the end-user experience.
- **Scalability**: the online advertising ecosystem delivers around a trillion ads every day. The protocol must be able to operate at this scale.
- **Seamless integration**: the protocol must allow its integration as part of the existing protocols and methods in online advertising without the need to modify them. In particular, it must be implementable in ad-tags and as part of the OpenRTB protocol, the two methods used for communication in the sell- and buy-side of the online advertising ecosystem, respectively.
- **Online and offline auditing**: the protocol must allow two types of auditing operations. On the one hand, online auditing that enables an entity to audit the validity of a received ad transaction in real-time. On the other hand, each ad transaction must create a log that can be audited in the future, so that misbehaving players can be identified at any moment in the future.

B. Protocol Overview

In essence, an ad transaction can be defined by a chain of individual actions taken by the involved players in the ad delivery process (See Figure 1). These actions are, in many cases, subject to the terms of a contract signed between two entities.

We propose to generate a digital chain that records the actions of every player involved in an ad transaction. Conceptually, the chain is formed by blocks. Each block is inserted in the chain by a player participating in the ad delivery process and summarizes the most relevant parameters associated with the actions taken by the player. Moreover, the block is signed with a private key that unequivocally identifies the player. Finally, a block is linked with the previous block to form the chain.

Following this simple protocol, the actions of the first player in the ad delivery process (i.e., the publisher) are recorded in the first block of the chain. This first block includes:

1) An universally unique identifier of the ad transaction. 2) Information identifying unequivocally the player to which the custody of the ad will be assigned so that this player is the unique one with rights to re-sell that ad. This identifier is the player’s domain name. 3) A foolproof identifier of the user to let the advertiser verify the final destination of the ad impression. This identifier is the IP address of the device requesting the ad. 4) Data fields, which are key-value pairs, where the actions of the publisher are registered. For instance, these may include the location of the ad space on the screen and the size of the ad space. Once all these data are compiled in the proper format, the publisher signs this block with its private key (note that the correspondent public key is publicly available). Then, the block is generated and sent to the second player in the chain indirectly through the user browser.

The first action of this second player (e.g., an SSP) upon the reception of the first block is to verify the signature. If the signature is correct, it generates a second block. Otherwise, it rejects the ad transaction and informs about it to the publisher. This second block is simpler than the first block. It includes the signature of the first block creating the binding between blocks to form the chain. In addition, it includes the key-value data fields recording the relevant information associated with the actions taken by the SSP as well as the identity (domain name) of the third player to which the custody of the ad will be delegated. These data are signed with the private key of the SSP, and thus, the second block is created. The chain, now formed by two blocks, is sent to the third player.

If the ad delivery process involves n players, the chain will have n blocks. From the second to the last block, all have the same format described in the previous paragraph. The only differences among blocks 2 to n correspond to the data fields (key-value pairs), which may be different for different types of players (e.g., the data fields from an SSP and an AdX might be different). The first block is the only one having a different format since it includes the ad transaction id and the
IP address of the device, as described above. The last block of a chain will be typically generated by the DSP, winning the last auction related to the ad transaction. Note that the advertiser winning the ad space associated with the transaction can verify the complete chain\(^5\) to audit that no information has been tampered during the process. Moreover, the \(i^{th}\) player in the chain can validate the blocks of players 1 to \(i-1\). Hence, a malicious player in position \(i\), which tries to modify previous blocks, can be easily identified by the advertiser or any player from position \(i+1\) since the signature of the modified blocks will be incorrect.

In the previous paragraph, we are considering a distributed auditing scheme where advertisers take the responsibility of auditing its own ad transactions. Alternative auditing schemes can be defined, e.g., a centralized auditing entity that receives the chains and performs a central auditing process, an auditing entity defined by publishers to validate the ad transactions associated with its websites. Note that it is up to the industry to choose the most appropriate auditing approach.

Finally, it is worth noting that this simple protocol meets the requirements defined above:

- unequivocal custody: only one player has the right to resell the ad at each step of the process.
- non-repudiability: every action reported by a player is recorded and signed with its private key. If a player is taking inappropriate actions, it would be registered and can be proved later.
- low latency: an entity executing our protocol needs to perform a hash and a signature, which in principle are simple actions. We explore this specific aspect in detail in Section V.
- scalability: the protocol operates at the level of individual transactions with low latency guarantees (See Section V) so that its scalability is guaranteed.
- seamless integration: as we will show in Sec III-D, our protocol can be implemented with both ad-tags (used by sell-side entities) and OpenRTB (used by buy-side entities).
- online and offline auditing: our proposal allows a player that receives the custody of an ad transaction to audit the received chain in real-time. The player can then reject the transaction if there is any problem with it. Offline auditing is also possible using the chains associated with finalized transactions.

\(^5\)We are assuming that DSP will deliver to the advertisers the chains associated with its delivered ads.

C. Protocol Details

In this subsection, we provide further technical details about the design of the protocol.

1) Unique identifier of ad transaction: The transaction identifiers need to be unique within each publisher domain. Popular websites are typically served from a distributed infrastructure of servers (e.g., a Content Distribution Network -CDN-) and thus would require to generate concurrent identifiers from multiple servers. Therefore, they need a systematic scheme to generate identifiers at high throughputs without collision.

In OpenRTB 3.0 and Ads.cert, the IAB mentions the need for having a unique transaction identifier to avoid replay attacks. However, it does not describe a format for it. We propose to use the Universal Unique Identifier (UUID) format described by RFC 4122 [21]. It is a well known and widely used standard for UUIDs, and there is available code to generate it in multiple programming languages.

A timestamp-based UUID is formed by 128 bits codifying three fields: a high-resolution timestamp (60 bits), a clock sequence (14 bits), and a node ID (48 bits). Popular domains present a high rate of ad requests. To meet this and future higher demands, we propose to provide a resolution of 1 ns. To this end, we borrow 7 bits from the clock sequence and assign them to the timestamp. That adjustment leaves another 7 bits for the clock sequence so that we can have up to 128 processes generating timestamps on a single server. With this format, the theoretical limit of the number of UUIDs per server is 128 billion per second. Similarly, we can codify timestamps up to the year 5623 if we use the UNIX epoch. Hence, it offers enough resolution and scalability to implement it even in the aforementioned distributed architectures such as CDNs, which may be serving tens of thousands of different domains.

In Ads.chain, we use the string representation of UUIDs—hexadecimal values of the 16 bytes (128 bits) separated with dashes after the fourth, sixth, eighth, and tenth byte—as transaction UUID and refer to them as tUUID. The tUUIDs will be generated by the publisher and tied to the ad transaction since the first signature block.

2) Blocks codification: A block in our protocol is formed by a set of data fields (key-value pairs) and the identity (domain name) of the next player in the chain, which is also represented in the format of a key-value pair. These data are certified by the digital signature of the player that generated them, which is also part of the block.

In order to include the block information in the ad transaction data, we only need to include three strings at every step: the custody field specifying the entity to which the sell is delegated, a keys-string that concatenates the keys of the fields included in the signature—separated with a special delimiter character—and the signature string codified in base64. The data signed is a string with the values corresponding to the keys in the keys-string, in the same order. Note that we do not need to include this string in the request as the values are already included in the request data, but we need the keys-string to be able to form it. The signatures are performed over the SHA-256 hash digest of the string representation of the block.

3) Handling Auction Processes: In an auction process, the custody of the transaction cannot be delegated until the process is concluded, and the winner of the auction (which will be the one receiving the custody delegation) is known.

Therefore, the entity launching the auction does not delegate the custody initially. Instead, it provides a temporary chain where its last block includes a temporary signature. This chain allows the participants in the auction to validate that the auction is run by the entity (usually an AdX) owning the
custody of the ad, as well as to check the information included in previous blocks.

When the auction is completed, the winner entity will receive the OpenRTB billing notice message, including the final chain of blocks that delegates the custody of the ad on the winner entity. The last block of this chain includes the domain name of the winner entity in the corresponding field.

If the auction corresponds to the last event of the ad delivery process, the winning entity, typically a DSP, generates the last block of the chain. This block signed by the DSP should include information regarding the advertiser, campaign id, and creativity associated with the ad delivered to the user.

4) Publisher signature in mobile apps: Ads.chain is designed to work independently of ad transactions on websites or mobile apps. However, transactions in mobile applications start on the user device with a request generally to a sell-side platform instead of to a publisher’s server. In this case, the app creates the Ads.chain block and requests a trusted server of the app’s publisher to sign it before sending it to the next intermediary in the custody chain. Note that many apps already interact with their backends, so adding this functionality requires low development effort.

D. Seamless Integration

Ads.chain can be seamlessly integrated into ad-tag calls and OpenRTB, which are the de-facto standard communication techniques used in the sell and buy sides of the online advertising ecosystem, respectively. Both ad-tag calls and OpenRTB messages specify the parameters in key-value pairs. Hence, we can embed the block fields (i.e., signature, custody, and keys-string) while maintaining the compatibility with current implementations. Specifically, in the ad-tag’s URL, the parameters are appended to the query string as there is no hierarchical structure. Whereas, in OpenRTB objects, the fields should be included in the Source object, as it is proposed in OpenRTB v3.0 for Ads.cert [22].

Entities not implementing Ads.chain would only need to ignore the associated fields. However, these entities would generate a gap in the chain of custody since they will not generate a block in the chain. We conjecture that with the incremental adoption of our protocol, entities failing to implement it may be penalized in different manners. Some players may pay less for ad transactions having gaps in the trust chain due to the associated trust issues. Other players may directly reject ad transactions that do not implement Ads.chain end-to-end. These penalties may be an incentive for a faster adoption of the proposed protocol.

Finally, we propose to use the private/public key pairs from the existing Public Key Infrastructure (PKI) on the web that gives support to HTTPS communications. These keys will serve to sign the blocks (with private keys) and perform signature audits (with public keys). Note that HTTPS is largely adopted by most players in the online advertising ecosystem, and they could implement our proposed protocol with their current keys.

E. Trust chain example

Figure 3 shows an example of how the final chain received by an advertiser looks like. Moreover, in the following link, can be accessed the format of the chain received by the different players of an ad transaction example involving a publisher web server, an SSP, an AdX, and a DSP winning the auction process and delivering the ad.

F. Ads.chain vs. Blockchain

Every ad transaction produces a chain of signature blocks. The demanding time constraints for delivering ads to users in real-time make impractical annotating these individual signature blocks of a chain as entries of a blockchain distributed ledger. Blockchain inspired solutions are more suitable for offline (not real-time) processes in the context of online advertising. For instance, they can be used for the verification of authenticity and uniqueness of the Ads.chain transaction chains.

6https://github.com/apastor/ads-chain-cpp-platforms/tree/master/ads-chain-examples
Ads.chain components required to implement We also implemented an external library that offers all the code in the delivery of ad transactions in programmatic advertising. col, we have built a lab scenario with the main entities present web browsers and added to curl in our tests.

in all of the entities as trusted. The CA is also installed in the certificates with the same Certificate Authority (CA), installed Ads.chain achieved with a simple implementation. We decided to use C++ as the programming language to have any dynamic functionality on the DSP's ad server, we serve backend in C++. As we are not interested (for our purpose) in the HTTPS server connected with FastCGI to a Cppcms [24] implemented using a common base structure: Nginx [23] as the platform involved in an ad delivery process. Both the entities of the lab prototype and the library are implemented in C++, and their associated code is publicly available on GitHub [9], [10].

A. Lab Prototype of Online Advertising Ecosystem

We have reproduced in our lab prototype a scenario similar to the one depicted in Figure 1. In particular, it is formed by a publisher’s website server, a sell-side entity acting as the publisher’s SSP, an AdX connecting the sell and buy sides, and a DSP as the buy-side entity. There is also an ad server for serving the final ad to the user’s browser upon the reception of the ad-tag of the auction winner.

We deploy each entity in independent instances in a private OpenStack with two compute nodes. The platforms are implemented using a common base structure: Nginx [23] as the HTTPS server connected with FastCGI to a Cppcms [24] backend in C++. As we are not interested (for our purpose) in any dynamic functionality on the DSP’s ad server, we serve the ads static files directly with Nginx from the ad server. We decided to use C++ as the programming language to have a better estimation of the optimal performance that can be achieved with a simple implementation.

As we propose to use the same keys for HTTPS and Ads.chain, we create a PKI with OpenSSL [25] and sign the certificates with the same Certificate Authority (CA), installed in all of the entities as trusted. The CA is also installed in the web browsers and added to curl in our tests.

Fig. 4. Image of the landing page of the mock website7 used for the publisher. The image only contains 1 ad space with ad-tag written in red in the frame.

IV. Ads.chain Implementation and Lab Prototype

To test the viability and performance of the proposed protocol, we have built a lab scenario with the main entities present in the delivery of ad transactions in programmatic advertising. We also implemented an external library that offers all the code components required to implement Ads.chain by any of the platforms involved in an ad delivery process. Both the entities of the lab prototype and the library are implemented in C++, and their associated code is publicly available on GitHub [9], [10].

The auction process in the ad exchange is simulated by launching the bid request to the DSP asynchronously. After 120 ms, the ad URL is extracted from the DSP’s bid response and returned to the SSP. Upon responding to the SSP, the ad exchange sends the billing notice to the DSP, updating the signatures to certify him as the winner of the auction and, in turn, delegating the custody of the ad transaction process.

B. Ads.chain library

The C++ Ads.chain library provides classes and functions for the cryptographic operations, network-related functionality, generating UUIDs based on the Unix timestamp, and logging times of execution. We use this library to implement the protocol in the publisher’s web server and programmatic platforms.

The library uses CMake for building the source and Conan [26] for dependency management. The main dependencies of the project are OpenSSL 1.1.1 [25] for the cryptographic operations, RapidJSON [27] for the data structure of the ad transaction information, the Boost Uuid module [28], and Poco [29] for caching, the HTTP requests and the logging. We also use Google’s Fruit [30] for dependency injection. In this section, we describe at a high level the design choices we made for the different functionalities implemented in the library to be used by the programmatic platforms. The library is available in a Github repository [9]. The interested reader can refer to the project repository for low-level details.

- **The crypto submodule** of the library provides C++ wrapper classes to OpenSSL. As an entity always signs with the same key, the Signer class receives the private key as a parameter in the constructor. The Verifier class, as is expected to verify signatures from different domains, will receive the public keys directly in the verify function. We have C++ high-level wrapper classes for the OpenSSL key structures that are especially handy for managing the cache of public keys.

For the sample website, we modified a static website template7 adapting it to the Model-View-Controller pattern of Cppcms to generate dynamic content. We use parameters in the query string to customize the petition to the publisher’s web server. This is the mechanism we use to control the number of ad-tags included in the response, whether to sign the requests, and a test id to include in the server-side logs to conduct our performance analysis (See Section V). All the parameters are optional, and the server returns by default one signed ad-tag. As the layout of the returned ads is not relevant for our purpose, the ad-tags are included as elements of an HTML list that the CSS will present with three elements per row in the lower part of the page. Figure 4 shows the landing page of the sample website used for the publisher.

The programmatic platforms are implemented as Cppcms servers as well. Their first task upon the reception of a request is to check if the fields with signatures are present in the request. If they do, they operate accordingly to the Ads.chain specification described in section III. If not, they process the request following the basic procedure of the platforms without signature verification.

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The auction process in the ad exchange is simulated by launching the bid request to the DSP asynchronously. After 120 ms, the ad URL is extracted from the DSP’s bid response and returned to the SSP. Upon responding to the SSP, the ad exchange sends the billing notice to the DSP, updating the signatures to certify him as the winner of the auction and, in turn, delegating the custody of the ad transaction process.

B. Ads.chain library

The C++ Ads.chain library provides classes and functions for the cryptographic operations, network-related functionality, generating UUIDs based on the Unix timestamp, and logging times of execution. We use this library to implement the protocol in the publisher’s web server and programmatic platforms.

The library uses CMake for building the source and Conan [26] for dependency management. The main dependencies of the project are OpenSSL 1.1.1 [25] for the cryptographic operations, RapidJSON [27] for the data structure of the ad transaction information, the Boost Uuid module [28], and Poco [29] for caching, the HTTP requests and the logging. We also use Google’s Fruit [30] for dependency injection. In this section, we describe at a high level the design choices we made for the different functionalities implemented in the library to be used by the programmatic platforms. The library is available in a Github repository [9]. The interested reader can refer to the project repository for low-level details.

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7the website template is obtained from freewebsitetemplates.com
- The **network submodule** has classes for retrieving and caching the public keys. The public key service caches the keys using the Poco Least Recently Used (LRU) cache with time expiration. If a key is not present, a data access object opens a brief SSL connection to the HTTPS port of the target domain server to retrieve and validate its HTTPS certificate. When a public key is requested to the domain, the public key service adds it to its cache. The network submodule also has functions to make HTTPS requests that return the body of the response and functions to transform query strings into RapidJSON document objects and vice versa. The programmatic platforms can use GET calls when the ad transaction parameters are encoded in the query string (generally on the sell-side) and POST calls when using the OpenRTB JSON objects. Besides, the submodule also has a handy function to re-create the string that was signed at a given level of the chain of custody. The fields that this function adds to the string are extracted from the `keys-string` field, so that it can be applied to any block in the chain, independently of the information signed by the platform generating each specific block.

- The **tools submodule** provides a time-based UUID generator and two stopwatch classes for taking time execution measurements. The UUID generator uses the Boost Uuid format [28] and follows the style of the generators of the library. We implemented it given the lack of a time-based generator in Boost. The first stopwatch is semi-automatic and logs the elapsed time from the object instantiation to the call to the stop function. The other stopwatch is fully automated using RAII (Resource Acquisition Is Initialization) [31] to compute the time between the object construction and destruction. Both stopwatches use the logger passed as argument to their constructor and allow to set extra fields for additional information of the configuration for which the times are taken.

V. PERFORMANCE EVALUATION

*Ads.chain* may slightly increase the processing time to render a web page since it forces to generate the ad transaction id, create a block, and sign it. Likewise, the processing time of ad transactions in programmatic platforms (SSPs, AdX, and DSPs) may increase with the use of *Ads.chain* due to the need to create a block and its associated digital signature.

As described in Section III-A, the extra delay incurred by *Ads.chain* must be limited to guarantee a negligible impact in (1) the load time of web pages—since it has been reported that a high page load time affects directly to user experience [32]—and (2) the overall time required to deliver an ad in the programmatic ecosystem. Increasing the delay associated with the delivery of programmatic ads may reduce the number of ads that are in practice rendered in web pages (and mobile apps).

In this section, we leverage our lab prototype and the specific functions implemented in the *Ads.chain* library (See Section IV-A) to evaluate the additional delay introduced by *Ads.chain* in the page serving time and the processing time of the ad transaction in programmatic platforms. To this end, we run experiments with and without *Ads.chain* and compare the obtained delays. Note that we measure the server processing time instead of taking measurements in the client since client measurements depend on additional factors unrelated to *Ads.chain*.

It is important to highlight that in our evaluation, we are assuming that *Ads.chain* executes sequentially to the rest of actions run by the web server or programmatic platforms, and thus we are reporting marginal delays for a worst-case scenario. In the real world, a server’s backend performs multiple tasks in parallel and asynchronously. Therefore, in practice, implementing *Ads.chain* will be transparent in terms of the delay as backends generally perform slower operations.

A. Page Serving Time Delay in publisher’s website

We define the Page Serving Time as the time between the instant the web server receives the query from the browser and the instant when the web server sends the page to the browser. As discussed in Section III, publishers implementing *Ads.chain* include the ad-tags with their signatures on the requested web page, and signatures are created upon the request of the request in real-time because they include information linked to the user making the request. Therefore, this metric allows us to objectively measure the impact that *Ads.chain* has on the overall page load time, and thus on the user experience.

We measure the increment in the page serving time introduced by *Ads.chain*’s signed ad-tags on a web page. We conduct our evaluation for different web server sizes. We run stress tests launching the server of our example website on instances of 2, 4, 8, and 16 vcpus from our private OpenStack (See Section IV-A). Moreover, as the signature has to be done for every ad-tag, we conduct tests for various numbers of ad spaces per page, from 1 to 30. We indicate the number of ads and whether to use signed ad-tags with parameters of the query string explained in Section IV-A. For launching the requests, we use another powerful server in which we run the curl petitions with several levels of concurrency to generate different throughputs. Specifically, we do 10 thousand curl petitions for the following configurations of parallel requests: 4, 8, 16, and 24, obtaining approximate throughputs of 180, 390, 550, and 870 requests per second.

The execution time of every request of the tests is logged at the server with an additional parameter to identify the test. Then, we compute the times’ percentiles for both runs of every test, with and without signed ad-tags. Figure 5 shows the increment in page serving time added by *Ads.chain* for the 50 and 95 percentile in every test for the least and most stressful throughputs. The results indicate that *Ads.chain* introduces overall delays below 5 ms, even in the most stressful considered scenario (30 ads per web page and 870 requests per second). A more detailed analysis of the results shows that, as expected, when the process of every request is done on a single thread, the increment in latency is linear with the number of ads, unless the server gets saturated. Moreover, we observe that the overhead introduced for the generation of UUIDs is in the order of µs.

Based on these results, we conclude that the impact of *Ads.chain* is transparent for the final user. These results on the publisher’s signature times are also valid for *Ads.cert*. 8
Ads.chain is negligible (<0.8 ms) in all cases at the 99 percentile. Moreover, the detailed analysis of the different components of this delay reveals that the most time-consuming task is the signature verification.

Based on this result, we conclude that Ads.chain has a negligible impact on the operation of programmatic advertising platforms.

VI. CONCLUSION

In this paper we present Ads.chain, a protocol that provides end-to-end traceability of individual ad transactions. It offers the required scalability to operate in the current online advertising ecosystem. Moreover, it uses de-facto standard technologies (ad-tags and OpenRTB), guaranteeing an easy and seamless integration in the current programmatic ecosystem.

Ads.chain extends the current effort of the IAB in providing traceability in online advertising through the Ads.txt and Ads.cert solutions. Ads.chain addresses the limitations of these techniques and provides (to the best of the authors’ knowledge) the first solution meeting the goal pursued by the IAB’s efforts to provide end-to-end traceability to ad transactions.

We demonstrate through extensive lab experiments that the impact of Ads.chain in the end-user experience browsing web pages and the operation of online advertising intermediaries is negligible.

Ads.chain code, as well as the additional code used for its evaluation, are publicly available. We encourage the research community and industry to provide feedback that helps to improve our solution and to conduct further measurements related to its performance. Our current effort focuses on finding interested stakeholders from the online advertising industry to conduct trials in real systems. Additionally, we will work on the definition of scalable auditing systems that automatically analyze the signature chains generated by Ads.chain to identify misbehaving entities.
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