A Metapolicy Framework for Enhancing Domain Expressiveness on the Internet

Gaurav Varshney and Pawel Szalachowski

SUTD, Singapore

Abstract. Domain Name System (DNS) domains became Internet-level identifiers for entities (like companies, organizations, or individuals) hosting services and sharing resources over the Internet. Domains can specify a set of security policies (such as, email and trust security policies) that should be followed by clients while accessing the resources or services represented by them. Unfortunately, in the current Internet, the policy specification and enforcement are dispersed, non-comprehensive, insecure, and difficult to manage.

In this paper, we present a comprehensive and secure metapolicy framework for enhancing the domain expressiveness on the Internet. The proposed framework allows the domain owners to specify, manage, and publish their domain-level security policies over the existing DNS infrastructure. The framework also utilizes the existing trust infrastructures (i.e., TLS and DNSSEC) for providing security. By reusing the existing infrastructures, our framework requires minimal changes and requirements for adoption. We also discuss the initial results of the measurements performed to evaluate what fraction of the current Internet can get benefits from deploying our framework. Moreover, overheads of deploying the proposed framework have been quantified and discussed.

Keywords: Domain, DNS, TLS, security policies, certificates.

1 Introduction

Domain names are a de facto standard way to identify computers, networks, services and other resources on the Internet. Domain security policies provide a way through which domain owners can specify the restrictions or rules that should be followed while accessing the computers, services or the resources represented by their domain names.

Currently, most of the domain security policies are either specified individually and published using the DNS infrastructure (e.g., SPF [10], DKIM [3], DMARC [13] — see subsection 2.3), or are specified at the domain web servers and communicated to *policy agents* ¹ via dedicated HTTP headers (e.g., HSTS [7]

¹ A policy agent is a software component that processes and enforces policies. It can be implemented within a user agent (such as a browser) or within a server software that supports a given policy.

or HPKP [5] — see subsection 2.3). Finally, the obtained security policies are enforced by policy agents.

In some cases, the enforcement of security policies is not automated and requires user's involvement (i.e., users are making policy decisions). One example of such a case is accepting or denying a secure connection to a domain that presented an expired certificate. However, most of the security policies are standardized and governed by software vendors and Internet communities, and domains cannot influence this process and have to just follow these standards for specification of their security policies.

The current mechanisms of security policy specification and enforcement are unsatisfactory and the future Internet requires a higher level of domain expressiveness for the following reasons.

- 1. Users are not proficient enough to make security decisions when a policy agent requires that [4]. In the previous studies, it was observed that most of the users do not even notice the browser security indicators (like padlock icons), or they ignore warnings displayed to them by browsers and just *clickthrough* [4,12].
- 2. For scalability reasons, software vendors and the Internet community can only introduce global and generic policies without focusing on domain-specific policies. Obviously, global policies might not fit all domains as domains have different resources, services, and business models. One concrete example is a non-security-critical website (like a news or an informational website) that mostly displays a read-only content to its visitors and makes profits on ads. In such a case, the website may want to relax its security policies and display the content (and ads) to visitors, even if some security properties are not met (e.g., the website's certificate is expired). On the other hand, an e-banking website may need a stricter security policy that must generate an error and does not let its users interact with the website in a case of certificate errors. Domains are usually more aware of their security requirements and therefore they are the right candidates for policymakers. Unfortunately, the current policy specifications barely consider domain-specific requirements as of today.
- 3. Another consequence of policies implemented by software vendors is that these policies may be inconsistently enforced by different software implementations, especially, when a policy specification leaves some choices to developers. For instance, if browsers do not implement policy enforcement uniformly, it may cause a situation where users can switch from one browser to another in order to overcome a generated policy error (actually, such a behavior has been observed in the past). Hence any new framework of security policy specification could benefit from providing a way through which security policies can be specified and managed by domains with a relatively less involvement of software vendors, user agents, or even the users.
- 4. Downgrade attacks, like stripping of policy headers, is another problem. Policy headers can be manipulated by a Man-in-the-Middle (MITM) adversary, or at client-ends via modified implementation (like malicious browser exten-

sions). Such a stripping of headers may lead to downgrade attacks, as an adversary can pretend to a client that the contacted domain does not deploy the given enhancement or policy. Third party extensions such as *Modify headers for Google Chrome* [11] can be used to modify or strip off HTTP headers making it easier to compromise the security policies at the application layer itself. Downgrade attacks (arising from backward compatibility [20]) can be possible if an exploitable backward compatibility is provided by the user agents.

5. Already a set of security policies is getting expressed via domains (see subsection 2.3). Hence, the Internet security may get benefited if domains can easily express and manage more security policies in future.

For a better expressiveness of domain level security policies, we propose a metapolicy framework through which domains can specify and manage a comprehensive set of their security policies. The proposed framework leverages the DNS infrastructure for publishing and accessing metapolicies, and the trust infrastructures of TLS or DNSSEC to provide the necessary layer of security.

2 Background

2.1 Domain Name System

Domain Name System (DNS) [15] is a decentralized and hierarchical system which stores information about domains. Different types of information are stored in different resource records. Some of the DNS resource record types include A record that points a domain to an IPv4 address, CNAME record that points one domain to another domain, TXT record for storing human-readable textual information, or MX records for point to domain's mail exchangers. DNS is mostly known for resolution of domain names to IP addresses, however currently, the DNS is getting utilized for storage of email policies, information on domain certificates, and other domain related information. Publishing policies over DNS has an inherent benefit. As most of the times a DNS resolution precedes the communication with a domain, it is easy for the initiating party to fetch security policies prior to the connection. This also removes the need for communication with any other party (only DNS servers are contacted).

DNS Security Extensions (DNSSEC) [14] is an extension of DNS which provides security to the DNS records by adding cryptographic signatures on top of it. For each DNS zone a zone signing key (ZSK) pair and ZSK's private key is used to sign the DNS records (the corresponding signatures are stored in special **RRSIG** resource records). The ZSK public key is stored in the **DNSKEY** record. The **DNSKEY** record is also signed with the private key of another key pair known as Key Signing Keys (KSK). The chain of trust is followed till the root. This addition of signature on top of DNS records help in verifying the origin of the DNS records and in identifying if the records have been tempered during the transit via a MITM attack.

2.2 Transport Layer Security

Transport Layer Security (TLS) is a key protocol that provides confidentiality and data integrity on the Internet. The TLS handshake protocol is the initial phase of the TLS, and it provides a way through which the clients and the servers can verify each other identity via X.509 digital certificates [9] issued to them by trusted certification authorities (CAs).

X.509 public-key infrastructure (PKI) certificates are issued to domains (such as google.com) by trusted intermediate CAs (such as Google Internet Authority G3) forming trust chains. The certificate contains the details of the domain's identity and the domain's TLS certificate's public key. The information in the certificate is trusted as a trusted CA has signed it asserting its correctness. X.509 certificates are either signed by other intermediate CAs or the root CA and then a root CA (such as GlobalSign) may have a self-signed X.509 certificate that is stored by clients. The chain of trust can be verified till root CA to identify if the certificate issued to the domain is valid. Usually, only servers have their certificates (i.e., clients' identities are not verified by servers).

As communicating parties can verify their identifies, the TLS handshake protocol allows them to securely exchange secret session keys. The session key is then used for the encryption of data over a communication session between the clients and the servers.

2.3 Security Policies

Email and the TLS PKI are two key areas in which domains are currently expressing their security policies. Email policies are one of the oldest policies that rely upon the DNS infrastructure.

The Sender Policy Framework (SPF) [10] helps the receiving email server to identify whether the host from which the email has been originated is an authorized entity to send an email to the domain's owner. Spam and phishing emails can be filtered using this email policy. To deploy this policy the domain needs to add a TXT record in its DNS zone file, specifying authorized addresses (that can send emails on behalf of the domain).

DomainKeys Identified Mail (DKIM) [3] helps in verifying the authenticity of a given email. A domain supporting DKIM digitally signs the outgoing emails using a private key. The domain publishes the corresponding public key in the DKIM-specific DNS TXT records. A receiving email server accesses the public key from the DNS records of the email's originating domain. This public key is used to verify the digital signature of the email. DKIM aims to ensure that the email has not been modified in the transit and is signed by the correct outbound email server authorized to send email for that domain.

Domain Message Authentication Reporting and Conformance (DMARC) [13] is a policy system that allows domain owners to specify whether SPF or DKIM or both should be used while sending the emails for that domain and what the receiving email servers should do in the case of policy failures.

DNS-based Authentication of Named Entities (DANE) [8] is a TLS PKI policy system that provides a way to authenticate TLS entities without a CA. DANE introduces new TLSA records, that are published over DNS and signed are via DNSSEC. TLSA records provide domains a way through which they can specify which CAs can issue a valid TLS certificate for a domain and which TLS certificate to use for a specific service. If a browser supporting DANE get a TLS certificate for a domain which is not from the domain specified CA list, then it can display a warning to the user mentioning that the connection with the domain is insecure.

Certification Authority Authorization (CAA) [6] provides a mechanism by which domains can specify (over DNS) which CAs can issue certificates for them and their subdomains. It is required for a CA to retrieve a CAA record for a particular domain and follow the rules and restrictions before issuing a certificate for that domain.

Some policies are defined using HTTP headers, instead of employing the DNS infrastructure. For instance, HTTP Strict Transport Security (HSTS) [7] allows web operators to mandate access to their websites on HTTPS connections. Whenever a browser accesses a website for the very first time the website replies back with an HSTS header that specifies that the subsequent connections should be conducted over HTTPS. The browser caches this information and connects the website only via HTTPS even if the user types a URL with HTTP specified. Around 4.37% of the domains enforce HSTS and there has been an increase of around 69% in its usage in Q2 2017 [16].

Similarly, HTTP Public Key Pinning (HPKP) [5] is a policy mechanism that allows domains to express their keys or keys of their CAs using HTTP headers. Around 0.71% of domains on an average are expected to have enforced HPKP. There has been an increase of 42% in the use of HPKP in Q2 2017 [16]. However, browser vendors decided to obsolete HPKP due to operational issues [12].

The deployment of the presented policies was recently analyzed by Szalachowski and Perrig [19], and Amann et al. [2].

3 Requirements and Challenges

In the current Internet, there is no comprehensive and secure framework through which the security policies can be easily defined, managed, stored, and published by domain owners. We identify a set of requirements that such a security policy framework should follow to enhance the domain expressiveness on the Internet. These include:

- 1. **Easy Management:** The new policy specification framework or protocol must make it easy for domains to specify, manage, and publish various security policies at one place with a sufficient level of security from known threats.
- 2. Security: The protocol must provide security for policies, i.e., policy agents can verify their authenticity (i.e., that a given policy was indeed produced by the corresponding domain).

- 3. **Deployability:** The protocol must be easy to deploy, manage, and use. Moreover, policies should be disseminated and secured using the existing infrastructures to minimize operational and deployment costs.
- 4. **Recoverability:** The protocol should not end up in an unrecoverable state. It must provide suitable recovery mechanisms in the case of a policy misconfiguration.
- 5. Adaptability: The protocol must be adaptable in the sense that it can coexist with the currently deployed mechanisms without needing major changes.
- 6. Availability: Policies should be highly available and publicly accessible.

4 A High-level Overview

To fulfill the above requirements we propose a comprehensive and secure metapolicy framework for specification and management of domain security policies. The framework allows the domains to specify, manage all the existing domain-level security policies as a metapolicy. Metapolicies are published in DNS and are secured using the existing TLS or DNSSEC PKI infrastructure.

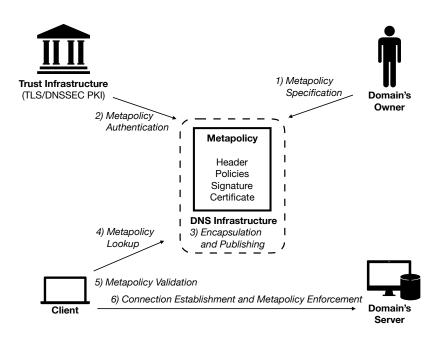


Fig. 1. A high-level overview of the metapolicy framework.

A high-level abstract overview of the proposed metapolicy framework is given in Figure 1 and the sequential workflow is described as follows.

- 1. **Metapolicy Specification:** The domain-level policies are specified by the domain owners using the policy specification format of the metapolicy framework (details of the metapolicy format is given section 5).
- 2. Metapolicy Authentication: The metapolicy is then signed using the domain's X.509 certificate private key or DNSSEC key. Since the domain's TLS certificate (or the DNSSEC key) can be verified, the domain binding with the metapolicy can be verified too.
- 3. Encapsulation and Publishing: Finally the signed metapolicy gets published in the DNS. To this end, the metapolicy has to be encoded as resource records. Publishing metapolicy in the DNS decreases the infrastructure cost and latency.
- 4. **Metapolicy Lookup:** Policies can then be queried by policy agents whenever a domain is going to be visited by a user (i.e., when a DNS resolution for a domain takes place).
- 5. **Metapolicy Validation:** The metapolicy's signature is verified using the domain's TLS certificate public key or the DNSSEC public key. All information required to validate the metapolicy is published as its part.
- 6. Connection Establishment and Metapolicy Enforcement: Once the metapolicy is verified the content of the metapolicy (individual security policies) are extracted and the specifications are enforced by the policy agents during the access to the domain's services and resources.

5 Details of the Framework

In the proposed framework all the domain security policies are included within a single metapolicy. Every metapolicy consists of:

- Header: This section contains metadata about the metapolicy.
- Policies: This section contains the actual content of the various security policies which are specified by the domain owner.
- Signature: This section contains a signature created using the domain's TLS certificate key or DNSSEC key over the metapolicy header and the policies section.
- Certificate: This section contains the domain's TLS certificate chain which is necessary to verify the authenticity of the created signature (i.e., whether the metapolicy was signed by the correct domain). When the metapolicy is signed with the DNSSEC key this field is empty, as the DNSSEC key of the domain can be obtained through the DNSKEY record.

The Header section contains the basic metadata about the metapolicy. In particular, it includes the following:

- Domain name on which the metapolicy is applicable. This is stored as a string.

- Version number of the metapolicy. The version increments when the metapolicy changes and an update happens. The version is represented as an integer.
 For example, a value of 1 in Version will represent the first version of the metapolicy.
- Valid From, Valid To dates in the *mm/dd/yyyy* format to specify the time period in which the metapolicy is considered as valid. Time is expressed in the UTC standard.
- Parts specify the number of DNS TXT records (see below) that needs to be downloaded to get the contents of the complete metapolicy. If the complete metapolicy can be wrapped up in 512 bytes the value of Parts is set to 1 else it will always be greater than 1 and will correspond to the number of TXT records needed to store the complete metapolicy. This field is required to encapsulate and decapsulate metapolicies over DNS protocol.
- Subdomains section lists the subdomains which will also follow the specified policies. Hence inheritance is provided as the information of whether the subdomains will follow the domain policies can also be specified in the metapolicy. This section can store subdomain names as a comma-separated list (it can be also a *wildcard* domain).

The **Policies** section contains the actual content of domain security policies. Each policy has to specify these fields in the domain's metapolicy:

- ID specifies a unique RFC number of a specific security policy.
- Specification section contains the actual content of a policy.
- Fail section instruct the clients about what they should do if a policy failure happens (an error in a policy specification or an error during its enforcement). The failing function can be either hard, soft, or ignore instructing the policy agent, that if a policy failure happens, the client should either immediately terminate the connection (hard), or soft-fail (soft) and show a warning to the user, or just ignore this policy failure and proceed normally. Domains can also instruct clients to do error reporting to a set of email addresses in case of failures.

The Signature section stores the signature computed over the metapolicy Header and Policies sections. The key used for signing the metapolicy corresponds to the private key(s) of the domain's TLS certificate or domain's DNSSEC key.

The last section of the metapolicy is the **Certificate** section that stores the domain's X.509 certificate chain (i.e., domains certificate and certificates of intermediate CAs). This certificate chain is used by the policy agents for validation of the domain's TLS certificate and the signature of the metapolicy. The storage of all the certificates (required to establish the chain of trust) in the domain's metapolicy avoids the extra efforts of locating and downloading these certificates by the policy agents. When the metapolicy is authenticated with the DNSSEC key this section is empty. Finally, the complete metapolicy is published via DNS. To do so, it has to be encapsulated into DNS resource records. A natural resource record type to store an arbitrary information is TXT. However, as shown by Szalachowski and Perrig [19] to transmit resource records reliably, they should not exceed 512 bytes. Therefore, if the total size of the metapolicy exceeds 512 bytes the metapolicy record is stored in parts up to 512 bytes each. The first part is published at _metapolicy.<domain_name> and the policy agents learn the number of parts by accessing the value of the Parts field from the metapolicy header (located in the first part). Other parts of a metapolicy are accessed by querying <part_number>._metapolicy.<domain_name> (e.g., 2._metapolicy.fb.com).

An example policy is shown in Figure 2.

```
Header:
   Domain: a.com
   Version: 1
   Valid From: 12/09/2016 UTC
   Valid To: 12/09/2018 UTC
   Parts: 1
   Subdomains: example.a.com, verbal.a.com
Policies:
   Id: 7288
   Specification: v=spf1 a include:aspmx.googlemail.com ~all
   Fail: hard, report@a.com
   Id: 6376
   Specification:v=DKIM1; k=rsa; p=TAMAfMAOGCSqGSIb3DQLOGE...
   Fail: soft, report@a.com
Signature: 9243152cd53fe3d1...
Certificate: MIIEBDCCAuygAwIBAgIDAjJ...
```

Fig. 2. An example of the metapolicy.

5.1 Metapolicy Lifetime

Creation A domain creates its metapolicy by specifying the security policies in the format specified in Figure 2. The domain then digitally signs the metapolicy with the private key(s) associated with its X.509 TLS certificate or with its DNSSEC private key. Finally, the signed metapolicy is published in the DNS as a series of TXT records.

Querying and enforcing meta policies Whenever a policy agent receives a request to connect to a domain it obtains the domain's metapolicy (if not cached) from the DNS TXT records of that domain. However, if the metapolicy for a domain has already been cached by the policy agent only the first DNS TXT record gets downloaded. The cached metapolicy is utilized and the complete metapolicy from the DNS does not get downloaded if the version of the metapolicy in the DNS is not higher than the version of the cached metapolicy.

Integrity and authenticity of the metapolicy content are guaranteed by the digital signature. To validate a metapolicy the policy agent must verify the **Signature** with the public key available from the domain's TLS certificate or DNSSEC. The client must also verify the domain's TLS certificate by validating the trust chain. If the signature verification succeeds the content of the specific security policies (identified by their ID) are fetched and enforced by the policy agent. Policy failures are handled and reported depending on the failing scenario specified (Fail).

A pseudocode that describes querying and enforcing of metapolicies is given in algorithm 1.

Updates and Recovery An update happens when at least one of the metapolicy section needs to be updated. The changes can be modifications of critical parameters (like adding or removing of security policies); update of the Valid From and Valid To field etc... In all cases, the metapolicy Version needs to be updated and a new signature must be calculated and placed in the Signature field of the metapolicy.

In the case when a cached metapolicy expires (i.e., the current date is greater than Valid To) the policy agent will fetch a new metapolicy published by the domain in the DNS. If by any chance the domain has not published a new metapolicy (a metapolicy with higher Version) the policy agent will use the cached metapolicy and report it to the domain. Because the policy agent queries the metapolicy header during each DNS query (i.e., each connection), it will download the newly published metapolicy once it finds that the Version number of the metapolicy in DNS is higher than that of the one stored in its local cache.

If the private key of the domain's TLS certificate or DNSSEC gets compromised or lost the last metapolicy published by the domain will still remain valid. This is because the policy agents can still verify the metapolicy using the domain's public key which will hold true until the TLS certificate corresponding to the compromised key gets revoked or a new DNSSEC key pair is generated and published. The certificate revocation does not affect the metapolicy framework because the policy agents who have already cached an old metapolicy will not be verifying the chain of trust again and whenever they find a higher version of metapolicy published in the DNS they will use the new chain of trust to validate the domain's new TLS certificate or DNSSEC key which is used to sign the metapolicy. Also, the metapolicy framework does not get affected when some of the intermediate CAs (in the domain's TLS certificate chain of trust) go out of business for the same reason. However, whenever a new TLS certificate is

Algorithm 1: Querying and Enforcing Metapolicy

```
M<sub>Domain</sub>: Domain's metapolicy
```

S_{Policy}: Metapolicy's signature

```
\mathtt{DNS}_{\mathtt{TXT}}: DNS TXT records storing the domain's metapolicy.
```

DNS_{TXT Part 1}: The first part of the metapolicy's DNS TXT record containing the metapolicy's header information.

 ${\tt M}_{\tt Domain}({\tt Cache}) \colon {\rm Client\ cached\ version\ of\ Domain's\ metapolicy\ specifications}.$

 ${\tt Cache: Client's/Server's local storage to store the metapolicy.}$

Policy: Stores the content of a security policy.

Return: Stores the execution status of the metapolicy querying and enforcement operations.

ID: ID represents the RFC number of a specific security policy.

Cached(X) : Checks if the metapolicy for domain X is cached in the client's local storage.

FetchContent(X): Fetches the content of a security policy identified by ID X. Verify(X): Verify if the signature (S_{Policy}) of the metapolicy (represented by X) is valid using the domain's TLS Certificate or DNSSEC key.

Delete(X): Deletes the contents of the metapolicy X from the client's cache. Enforce(X): Enforce the specifications of policy X and return the execution status as either success or failure (soft, hard, ignore).

if $Cached(M_{Domain})$ then

```
M_{Domain} \leftarrow DNS_{TXT Part 1}
     if M_{Domain}(Cache) \rightarrow Version is equal to M_{Domain} \rightarrow Version then
         Policy \leftarrow FetchContent(ID) (From Cache)
         Return \leftarrow Enforce(Policy)
     else
         Delete(M_{Domain}(Cache))
         M_{Domain} \leftarrow DNS_{TXT}
         if Verify(S_{Policy}) == Success then
              Policy \leftarrow FetchContent(ID)
              Cache \leftarrow M_{Domain}
              Return \leftarrow Enforce(Policy)
         else
          | Return \leftarrow hard
         end
    end
else
     \mathrm{M}_{\mathrm{Domain}} \gets \mathrm{DNS}_{\mathrm{TXT}}
    if Verify(S_{Policy}) == Success then
         Policy \leftarrow FetchContent(ID)
         Cache \leftarrow M_{Domain}
         Return \leftarrow Enforce(Policy)
     else
         Return \leftarrow hard
    end
\mathbf{end}
```

introduced the domain must remove the old certificate from the Certificate section and add the new certificate belonging to the new chain of trust. If with that change a domain's private/public keypair was changed, the domain must also update the old signature in the Signature section.

6 Analysis

6.1 Security Analysis

We assume that the first connection to the DNS is not under attack because if that is the case then a MITM adversary could just censor all subsequent communication and clients would never reach a metapolicy. We also assume that the user's system and the policy agent are trusted and that the system is free from host-based malware. Study of the effects of malware on the security of the proposal is currently out of the scope of the current research work.

With the above assumptions the metapolicy framework can be compromised when: (1) the policy agents or user does a wrong decision in case of policy failures, or (2) when the key used to sign the metapolicy gets compromised or used PKI is compromised.

For the first case, as all the information resides within the metapolicy and is specified by the domain owners; the policy agents or the users are not involved in decision making during policy failures. Hence attacks arising from user's bad decision making or from provisions of backward compatibility cannot happen if the domain does not specify to take a user input or want the policy agents to fallback during a policy failure. The possibility of downgrade attacks also gets reduced with the use of our metapolicy framework because the policy agents can cache the metapolicy records.

An adversary able to compromise a domain's private key, or able to obtain a malicious certificate on behalf of the domain can create a malicious metapolicy. In such a case, the domain owner can initiate the recovery mechanisms, revoking the malicious public key and establishing a new metapolicy.

6.2 Deployability

As the proposed scheme uses the TLS or DNSSEC key(s) for signing the metapolicy, all the domains supporting DNSSEC or TLS can deploy the proposed metapolicy framework. To find out how many domains can possibly deploy our scheme we conducted an experiment over a dataset of 120K top websites received from the Alexa top 1 million domains list [1]. We used the tls-scan library [17] to obtain these statistics. From our experiments, we identified that around 77.8% websites support TLS and 2.6% of the websites supports DNSSEC. Hence, a large fraction of websites can implement the metapolicy framework even today.

We also measured the percentage of domains which may get benefited via metapolicy framework. To calculate the same we conducted an experiment to obtain the number of websites that today implement a security policy that can be expressed by our metapolicy framework. The host command of Linux was used to fetch the records of various email and TLS policies from DNS. The outcomes of the experiment are given in Table 1. The obtained results indicate that majority of domains (around 76.3%) sets at least one security policy today.

Policy	Supporting	Percentage	
	Websites		
SPF	68213	56.00%	
DKIM	56704	46.60%	
DMARC	11973	9.80%	
DNSSEC	3217	2.60%	
CAA	1213	0.99%	
DANE	34	0.03%	

Table 1. Number of websites supporting various domain policies

Table 2. Number of domains supporting multiple security policies

# of Policies	# of Domains	Percentage	# of Policies	# of Domains	Percentage
At least 1	92801	76.30%	1	53057	43.62%
At least 2	39744	32.67%	2	31755	26.24%
At least 3	7989	6.50%	3	7233	5.94%
At least 4	756	0.62%	4	699	0.57%
At least 5	57	0.05%	5	50	0.04%
At least 6	7	0.01%	6	7	0.01%

6.3 Overheads

Metapolicy Size Size of a TLS certificate chain is a dominant factor in the overall size of a given metapolicy. To find out how big this overhead is we conducted an experiment. During this experiment, we downloaded all certificate chains which are required for domain's TLS certificate validation for a domain set. We used the **openss1** tool for this purpose. The experiment was performed on the Alexa top 13k websites. We found that the average size of the of a certificate chain needed for a domain's TLS certificate validation is around 4.75 KB. Thus on average, a metapolicy protected with a TLS certificate will have to contain 4.75 KB for a certificate chain. (Note that policy agents do not have to store certificates of validated policies.)

To calculate the size of an average metapolicy we did an analysis of the results obtained in subsection 6.2. As shown in Table 2, around 33% of websites deploy at least two or more policies. With the results from Table 1 we can assume that on average policies implemented by domains will be either a SPF, DKIM or DMARC policy. We used this analysis to identify the size of an average metapolicy record. We created multiple metapolicy records with these three policies specified in it and stored domain's TLS certificate chain and a computed signature. We calculated the average size of metapolicy to be around 5.4 KB. Thus, on average, a metapolicy would require about 11 TXT records to be encoded.

Latency Another overhead is the additional time needed for fetching a metapolicy. To calculate this overhead we performed an experiment sending DNS queries to calculate the time needed for fetching a single DNS TXT record. We identified that accessing it takes around 20 ms on an average, on a system having a network download speed of 13 Mbps. In the same setting obtaining additional 10 records, even sequentially (what is the worst case), increases the latency by 200 ms (for the records queried in parallel that should be around only 20 ms). Hence, the proposed metapolicy framework introduces an acceptable overhead on top of a normal DNS query for a metapolicy. However, once the metapolicy is cached only the first 512 bytes of the metapolicy (the first part) gets downloaded by the policy agents.

Computational overhead To identify the overheads of the certificate validation process (that will happen when the metapolicy's signature will be verified at the client) we used the **OpenSSL** library and the certificate chains obtained in the previous experiment. In our tests, we identified that it takes 4 ms on an average for the certificate chain and signature validation process. Hence the metapolicy verification introduces an acceptable overhead to a standard connection establishment.

7 Implementation

To implement a prototype of the proposed metapolicy framework, we used the Bind open source DNS server implementation. We configured a Bind to serve as a private DNS server. It ran under Ubuntu 16.04 equipped with Intel (R) Core (TM) i7-7600U CPU (2.8 GHz) with 8 GB of RAM. We created and published (in TXT records) an example metapolicy. We also prototyped a policy agent able to fetch and process metapolicies. Our experiments confirm the feasibility of our framework and deployability even with currently existing tools and libraries.

8 Related work

Despite important of the topic, there has been a little work in the area of domain expressiveness over the Internet. In particular, we are not aware of any work

which directly fits into our line of research work described in this paper. One example of domain expressiveness system is DMARC [13]. It is a policy system that allows domain owners to manage their email security policies (SPF and DKIM, specifically). DMARC, similarly to our system, uses DNS for publishing its policies. However, the scheme does not provide any security and has limited functionality.

Another related system is PoliCert [18] which enhances the security of the existing TLS PKI infrastructure by allowing domain owners to decide and define policies that govern the usage of their TLS certificates. The authors introduced the concept of subject certificate policies that provide domains a way to specify trusted CAs, their update criteria, error handling and private key loss mechanisms. To take care of a single CA compromise they introduced the concept of multiple signature certificates that allows multiple CAs to sign a certificate. PoliCert relies on verifiable public logs, thus it needs to introduce a new infrastructure.

9 Conclusions

In this paper, we presented a metapolicy framework for enhancing the domain expressiveness on the Internet. Our proposal provides domains a mechanism to define and manage domain related security policies themselves. All the metapolicies related to a domain and which the domains want to enforce can be mentioned in a metapolicy which is signed by the domain's private key corresponding to the domain's TLS certificate or DNSSEC key. The metapolicy is published as a series of DNS TXT records in the domain's DNS zone. Therefore, no new infrastructure is required, and our scheme can be deployed today.

The framework makes it easy for domains to manage the policy themselves. It also reduces the chances of a downgrade attack due to incorrect choices which can be made by a user or its user agent, because a fail-over mechanism as specified in the metapolicy has to be followed and neither the software or the user decides the fate of a policy failure. It also provides a simple way of management and specification of policies including the HTTPS related security policies likes HSTS or HPKP or Email related security policies including SPF, Sender ID, DMARC, DKIM or other security policies including the DANE or CAA. In future, we believe that more security policies can be expressed by domains through our proposed metapolicy framework.

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