ADD
Internet-Draft
Intended status: Standards Track
Expires: September 7, 2020

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March 6, 2020

DNS-over-HTTPS and DNS-over-TLS server Discovery and Deployment Considerations for Home and Mobile Networks
draft-btw-add-home-01

Abstract

This document discusses DoT/DoH deployment considerations for home networks. It particularly sketches the required steps to use DoT/DoH capabilities provided by local networks.

One of the goals of this document is to assess to what extent existing tools can be used to provide a DoT/DoH service. As an outcome, new DHCP and Router Advertisement Options are specified in order to convey a DNS Authentication Domain Name.

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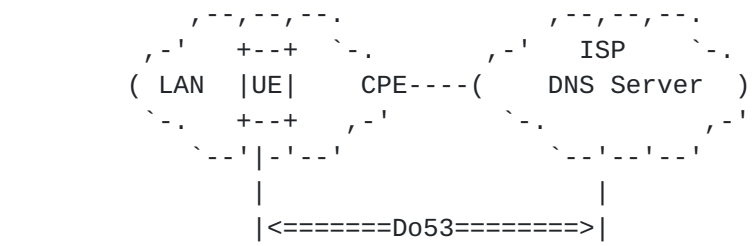
1. Introduction

Internet Service Providers (ISPs) traditionally provide DNS resolvers to their customers. Typically, ISPs deploy the following mechanisms to advertise a list of DNS Recursive DNS server(s) to their customers:

- Protocol Configuration Options in cellular networks [TS.24008].
- DHCP [RFC2132] (Domain Name Server Option) or DHCPv6 [RFC8415][RFC3646] (OPTION_DNS_SERVERS).
- IPv6 Router Advertisement [RFC4861][RFC8106] (Type 25 (Recursive DNS Server Option)).

The communication between a customer's device (UE) (possibly via Customer Premise Equipment (CPE)) and an ISP-supplied DNS resolver takes place by using cleartext DNS messages (Do53, [I-D.ietf-dnsop-terminology-ter]). Some examples are depicted in Figure 1. In the case of cellular networks, connectivity can be provided to a UE or to a CPE. Do53 mechanisms used within the LAN are similar in both fixed and cellular CPE-based broadband service offerings.

(a) Fixed Networks



(b) Cellular Networks

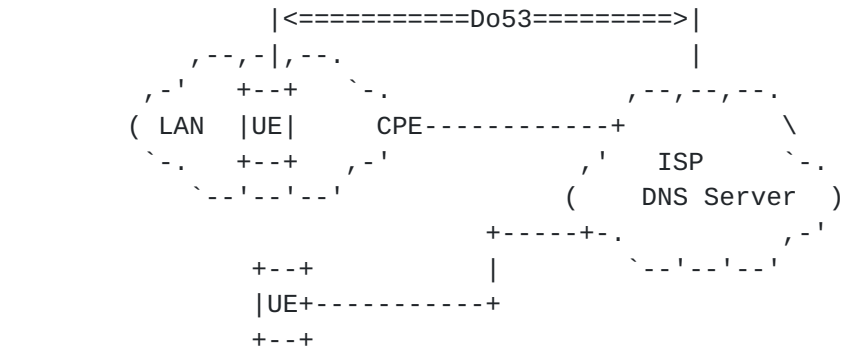


Figure 1: Sample Legacy Deployments

ISPs use DNS to provide additional services such as (but not limited to) malware filtering, parental control, or VoD (Video on Demand) optimization. DNS is also a central component for mastering the quality of experience for current latency-sensitive services, but also emerging ones (such as those services that pertain to the Ultra Reliability and Low Latency Communications (uRLLC) or Enhanced Mobile Broadband (eMBB).

For example, the latency targets set in the context of 5G are 1ms (uRLLC) and 4ms (eMBB). An ISP will be able to address such demanding latency requirements assuming the corresponding services rely upon resources (network, compute, storage) that are located as close to the user as possible (e.g., by means of Edge Computing

techniques and resources). Such latency requirements are likely to be addressed by means of optimized designs (DNS, in particular), too.

Relying upon local DNS resolvers will therefore contribute to meet the aforementioned service requirements. The use of external resolvers is likely to induce an extra service delay which exceeds by far the service target.

This document focuses on the support of DNS-over-HTTPS (DoH) [RFC8484] or DNS-over-TLS (DoT) [RFC7858] in local networks. In particular, the document describes how a local DoH/DoT server can be discovered and used by connected hosts. This document specifies DHCP/RA options that allows DNS clients to discover local DoT/DoH servers. Section 4 describes DHCPv4, DHCPv6 and RA options to convey the authentication domain name information (ADN, defined in [RFC8310]).

Some ISPs rely upon external resolvers (e.g., outsourced service or public resolvers); these ISPs provide their customers with the IP addresses of these resolvers. These addresses are typically configured on CPEs using the same mechanisms listed above. This document permits such deployments. It is up to an ISP to decide which list of DNS resolvers to advertise to its serviced devices.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119][RFC8174] when, and only when, they appear in all capitals, as shown here.

This document makes use of the terms defined in [RFC8499] and [I-D.ietf-dnsop-terminology-ter].

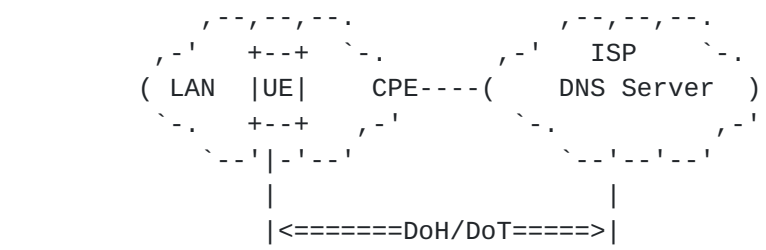
'DoH/DoT' refers to DNS-over-HTTPS and/or DNS-over-TLS.

3. Sample Deployment Scenarios

ISPs have developed an expertise in managing service-specific configuration information (e.g., CPE WAN Management Protocol [TR-069]). For example, these tools may be used to provision authentication domain name information (ADN, defined in [RFC8310]) to managed CPEs if DoH/DoT is supported by a local network similar to what is depicted in Figure 2.

DNS clients may try to establish DoH/DoT sessions with discovered DNS servers to determine whether these servers support DoH and/or DoT (Section 5). Alternatively, a DNS client may discover whether the DNS server in the local network supports DoH/DoT by using the mechanism discussed in Section 6.

(a) Fixed Networks



(b) Cellular Networks

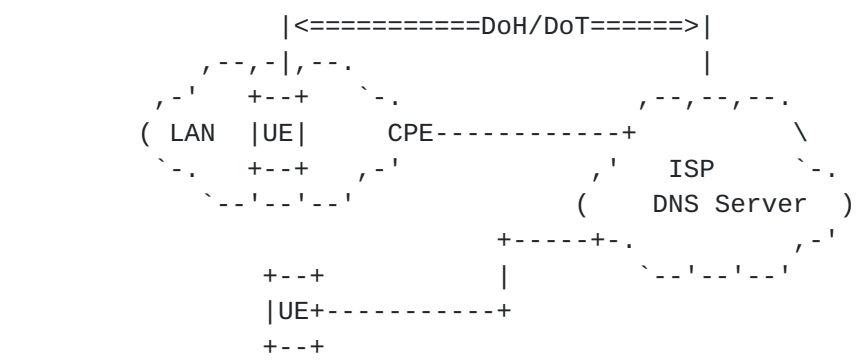


Figure 2: DoH/DoT in the WAN

Figure 2 shows the scenario where the CPE relays the list of DoT/DoH servers it learns for the network by using mechanisms like DHCP or a specific Router Advertisement message. In such context, direct DoH/DoT sessions will be established between a host serviced by a CPE and an ISP-supplied DoT/DoH server (see the example depicted in Figure 3 for a DoH/DoT-capable host).

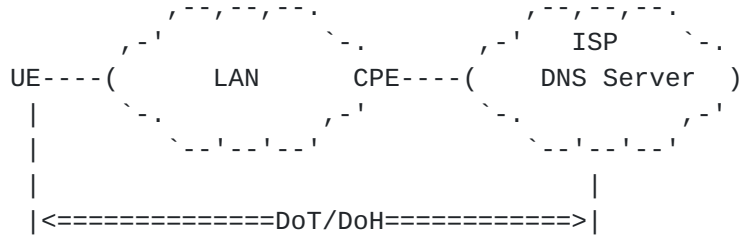


Figure 3: Direct DoH/DoT Sessions

Figure 4 shows a deployment where the CPE embeds a caching DNS forwarder. The CPE advertises itself as the default DNS server to the hosts it serves. The CPE relies upon DHCP or RA to advertise itself to internal hosts as the default DoT/DoH/Do53 server. When receiving a DNS request it cannot handle locally, the CPE forwards the request to an upstream DoH/DoT/Do53 resolver. Such deployment is required for IPv4 service continuity purposes (e.g., [I-D.ietf-v6ops-rfc7084-bis]) or for supporting advanced services within the home (e.g., malware filtering, parental control, Manufacturer Usage Description (MUD, [RFC8520] to only allow intended communications to and from an IoT device). When the CPE behaves as a DNS forwarder, DNS communications can be decomposed into two legs:

- The leg between an internal host and the CPE.

- The leg between the CPE and an upstream DNS resolver.

Also, an ISP that wants to offer DoH/DoT to its customers may enable DoH/DoT in both legs as shown in Figure 4. Additional considerations related to this approach are discussed in Section 7.

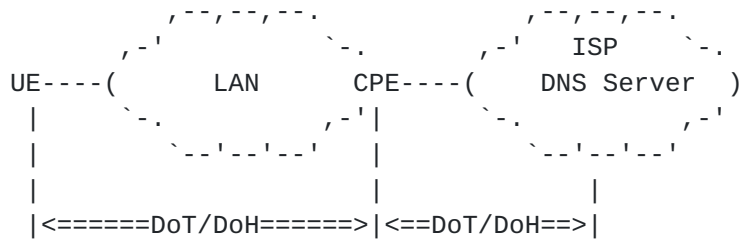


Figure 4: Proxied DoH/DoT Sessions

4. DNS Reference Identifier Option

This section describes how a DNS client can discover the ADN of local DoH/DoT server(s) using DHCP (Sections 4.1 and 4.2) and RA (Section 4.3).

As reported in Section 1.7.2 of [RFC6125]:

> "few certification authorities issue server certificates based on IP addresses, but preliminary evidence indicates that such certificates are a very small percentage (less than 1%) of issued certificates".

In order to allow for PKIX-based authentication between a DNS client and a DoH/DoT server while accommodating the current best practices for issuing certificates, this document allows for configuring an

authentication domain name to be presented as a reference identifier for DNS authentication purposes.

The DNS client establishes a DoH/DoT session with the discovered DNS IP address(es) (Section 5) and uses the mechanism discussed in Section 8 of [RFC8310] to authenticate the DNS server certificate using the authentication domain name conveyed in the DNS Reference Identifier.

If the DNS Reference Identifier is discovered by a host using both RA and DHCP, the rules discussed in Section 5.3.1 of [RFC8106] MUST be followed.

4.1. DHCPv6 DNS Reference Identifier Option

The DHCPv6 DNS Reference Identifier option is used to configure an authentication domain name of the DoH/DoT server. The format of this option is shown in Figure 5.

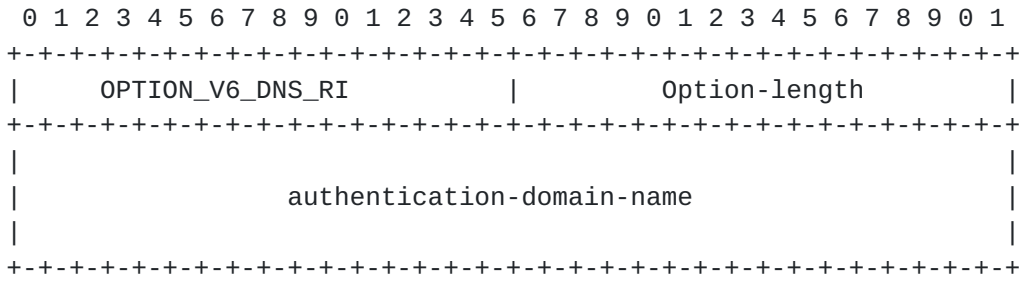


Figure 5: DHCPv6 DNS Reference Identifier Option

The fields of the option shown in Figure 5 are as follows:

- Option-code: OPTION_V6_DNS_RI (TBA1, see Section 9.1)
- Option-length: Length of the authentication-domain-name field in octets.
- authentication-domain-name: A fully qualified domain name of the DoH/DoT server. This field is formatted as specified in Section 10 of [RFC8415].

An example of the authentication-domain-name encoding is shown in Figure 6. This example conveys the FQDN "doh1.example.com.".

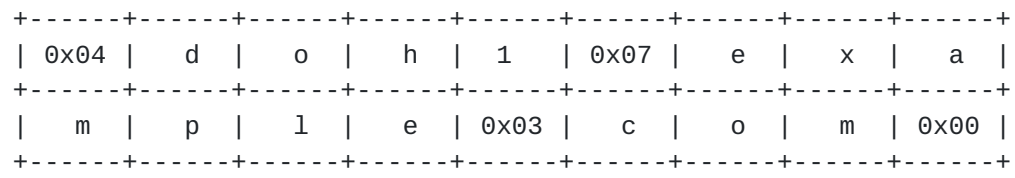
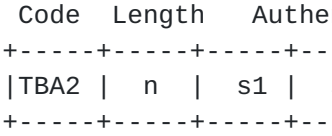


Figure 6: An example of the authentication-domain-name Encoding

4.2. DHCP DNS Reference Identifier Option

The DHCP DNS Reference Identifier option is used to configure an authentication domain name of the DoH/DoT server. The format of this option is illustrated in Figure 7.



The values s1, s2, s3, etc. represent the domain name labels in the domain name encoding.

Figure 7: DHCPv4 DNS Reference Identifier Option

The fields of the option shown in Figure 7 are as follows:

- Code: OPTION_V4_DNS_RI (TBA2, see Section 9.2).
- Length: Includes the length of the "authentication domain name" field in octets.
- Authentication domain name: The domain name of the DoH/DoT server. This field is formatted as specified in Section 10 of [RFC8415].

4.3. RA DNS Reference Identifier Option

The IPv6 Router Advertisement (RA) DNS Reference Identifier option is used to configure an authentication domain name of the DoH/DoT server. The format of this option is illustrated in Figure 8.

Figure 8: RA DNS Reference Identifier Option

The fields of the option shown in Figure 8 are as follows:

- Type: 8-bit identifier of the DNS Reference Identifier Option as assigned by IANA (TBA3, see Section 9.3).
- Length: 8-bit unsigned integer. The length of the option (including the Type and Length fields) is in units of 8 octets.
- Reserved: This field is unused. It MUST be initialized to zero by the sender and MUST be ignored by the receiver.
- Lifetime: 32-bit unsigned integer. The maximum time in seconds (relative to the time the packet is received) over which the authentication domain name MAY be used as a DNS Reference Identifier. The value of Lifetime SHOULD by default be at least 3 * MaxRtrAdvInterval, where MaxRtrAdvInterval is the maximum RA interval as defined in [RFC4861]. A value of all one bits (0xffffffff) represents infinity. A value of zero means that the DNS Reference Identifier MUST no longer be used.
- Authentication domain name: The domain name of the DoH/DoT server. This field is formatted as specified in Section 10 of [RFC8415].

5. Locating DoH/DoT Servers

A CPE or a host relies upon discovery mechanisms (such as PCO, DHCP, or RA) to retrieve DoH and DoT servers' reachability information. In the various scenarios sketched in Section 3, Do53, DoH, and DoT may terminate on the same IP address (or distinct IP addresses as depicted in Figure 9). Terminating Do53/DoH/DoT on the same or distinct IP addresses is deployment-specific.

From an IP reachability standpoint, DoH/DoT servers SHOULD be located by their address literals rather than their names. This avoids adding a dependency on another server to resolve the DoH/DoT name. Concretely, if Do53/DoH/DoT terminate on same IP addresses, existing discovery mechanisms [RFC2132][RFC3646][RFC8106] can be leveraged to

learn the IP addresses of DoT/DoH servers while an authentication domain name is supplied by one of the options discussed in Section 4.

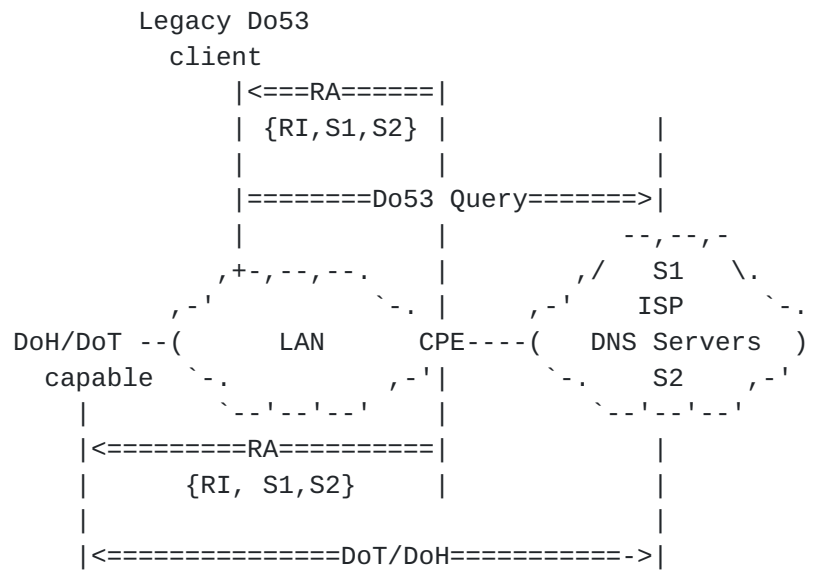


Figure 9: Locating DoH/DoT/Do53 using RFC8106

Additional considerations are discussed below for the use of DoH and DoT servers provided by local networks:

- If the DNS server's IP address discovered by using DHCP/RA is pre-configured in the OS or Browser as a trusted resolver, the DNS client may auto-upgrade to use the pre-configured DoH/DoT server tied to the discovered DNS server IP address. In such a case the DNS client may perform additional check out of band, such as confirming that the Do53 IP address and the DoH server are owned and operated by the same organisation.

- If the DNS reference identity (Section 4) is provided by means of DHCP/RA, the DNS client matches the domain name in the DNS Reference Identifier DHCP/RA option with the 'DNS-ID' identifier type within subjectAltName entry in the server certificate conveyed in the TLS handshake.

Additional options are discussed below:

- The Wi-Fi Alliance has released the Device Provisioning Protocol (DPP). If DPP is used, the configurator can securely configure devices in the home network with the local DoT/DoH server using DPP.

- If a CPE is co-located with security services within the home network, the CPE can use WPA-PSK but with unique pre-shared keys for different endpoints to deal with security issues. In such networks, [I-D.reddy-dprive-bootstrap-dns-server] may be used to securely bootstrap endpoint devices with the authentication domain name (ADN) and DNS server certificate of the local network's DoH/DoT server.

  The OS would not know if the WPA pre-shared-key is the same for all clients or a unique pre-shared key is assigned to the host. Hence, the user has to indicate to the system that a unique pre-shared key is assigned to trigger the bootstrapping procedure.

  If the device joins a home network using a single shared password among all the attached devices, a compromised device can host a fake access point, and the device cannot be securely bootstrapped with the home network's DoH/DoT server.

6. DNS-over-TLS and DNS-over-HTTPS Server Discovery Procedure

A DNS client discovers the DNS server in the local network supporting DNS-over-TLS and DNS-over-HTTPS protocols by using DNS-based Service Discovery (DNS-SD) [RFC6763]. DNS-SD provides generic solution for discovering services available in a local network. DNS-SD defines a set of naming rules for certain DNS record types that they use for advertising and discovering services. Section 4.1 of [RFC6763] specifies that a service instance name in DNS-SD has the following structure:

<Instance> . <Service> . <Domain>

The <Domain> portion specifies the authentication domain name (ADN). The <Service> portion of the DNS service instance name MUST be "_domain-s._tcp" or "_doh._tcp". If no DNS-SD records can be retrieved, the discovery procedure fails for this authentication domain name. However, before retrying a lookup that has failed, a DNS client MUST wait a time period that is appropriate for the encountered error (e.g., NXDOMAIN, timeout, etc.). If no DNS-SD records can be retrieved, the DNS client can try connecting to the pre-configured public DNS servers (if any).

If DoH is supported by the DNS server, the DNS client may request the URI resource record type [RFC7553] using the domain name discovered using DNS Reference Identifier DHCP/RA option (Section 4) to use the HTTPS URI scheme (Section 3 of [RFC8484]).

7. Hosting DoH/DoT Forwarder in the CPE

The following mechanisms can be used to host a DoH/DoT forwarder in the CPE:

- If a CPE is co-located with security services (e.g., malware filtering, parental control, MUD), the ISP can assign a unique FQDN (e.g., cpe1.example.com) and a domain-validated public certificate to the DoH/DoT forwarder hosted on the CPE. Automatic Certificate Management Environment (ACME) [RFC8555] can be used to automate certificate management functions such as domain validation procedure, certificate issuance and certificate revocation.

- Alternatively, the security service provider can assign a unique FQDN to the managed CPE. The DoT/DoH forwarder will act like a public DoT/DoH server but will only be accessible from within the home network. DNS queries received outside the home network must be discarded by the DoH/DoT forwarder. This behavior adheres to REQ#8 in [RFC6092], and must apply for both IPv4 and IPv6.

- If the ISP DoH resolver is pre-configured as a trusted resolver in browsers, the CPE is managed by the ISP, and the ISP has assigned a domain-validated public certificate to the DoH forwarder hosted on the CPE, the ISP can configure the CPE to convey the ISP DoH/DoT resolver IP addresses and the ISP DoH/DoT ADN in DHCP/RA to internal hosts (Section 4). If the ISP DNS server IP address is pre-configured in the browser as a trusted resolver, the DNS client auto-upgrades to use the DoH/DoT server tied with the discovered DNS server IP address.

  If the ADN in DHCP/RA is pre-configured in the OS or browser as a trusted resolver, the client auto-upgrades to establish DoH session with the ADN.

  Once the DoH session is established, the ISP DoH/DoT server uses HTTP redirection (Section 6.4.4 in [RFC7231]) to redirect the DNS client to the DoH forwarder hosted on the CPE. The DNS client uses Do53 to resolve the domain name in the redirected URI and eventually establishes DoH session with the DoH forwarder on the CPE.

8. Security Considerations

An attacker can get a domain name, domain-validated public certificate from a CA, host a DoT/DoH server and claim the best DNS privacy preservation policy. Also, an attacker within the home network can use the public IP address, get an 'IP address'-validated

public certificate from a CA, host a DoT/DoH server and claim the best DNS privacy preservation policy.

Because DHCP/RA messages are not encrypted or protected against modification in any way, their content can be spoofed or modified by compromised devices within the home network. An attacker can spoof the DHCP/RA response to provide the attacker's DoT/DoH server. Note that such an attacker can launch other attacks as discussed in Section 22 of [RFC8415]. Furthermore, if the browser or the OS is pre-configured with a list of DNS servers and some of which perform malware filtering while others do not, an attacker can prevent contacting the preferred filtering DNS servers causing a downgrade attack to a non-filtering DNS server, which the attacker can leverage to deliver malware.

The primary attacks against the methods described in Section 6 are the ones that would lead to impersonation of a DNS server and spoofing the DNS response to indicate that the DNS server does not support DoH or DoT. To protect against DNS-vectored attacks, secured DNS (DNSSEC) can be used to ensure the validity of the received DNS records received. Impersonation of a DoH/DoT server is prevented by validating the certificate presented by the DoH/DoT server. If DHCP/RA conveys an ADN, but the DNS-SD lookup indicates that the DNS server does not support DoH/DoT, the DNS client can detect the DNS response is spoofed.

The use of DoH/DoT also depends on the user's policies. For example, the user may indicate his/her consent to use (or not) the locally-discovered DoH/DoT server. The DNS client must adhere to these policies.

DoH/DoT servers discovered using insecure discovery mechanisms like DHCP/RA are used by a DNS client if the insecurely discovered DoH/DoT server is pre-configured in the OS or the browser.

If the insecurely discovered DoH/DoT server is not pre-configured in the OS or browser, its policy information must be cryptographically attested by the ISP (e.g., [I-D.reddy-dprive-dprive-privacy-policy]); user consent is required to use the locally-discovered DoH/DoT server.

DoT/DoH sessions with rogue servers spoofing the IP address of a DNS server will fail because the DNS client will fail to authenticate that rogue server based upon PKIX authentication [RFC6125] based upon the authentication domain name in the Reference Identifier Option. DNS clients that ignore authentication failures and accept spoofed certificates will be subject to attacks (e.g., redirect to malicious servers, intercept sensitive data).

9. IANA Considerations

9.1. DHCPv6 Option

IANA is requested to assign the following new DHCPv6 Option Code in the registry maintained in: https://www.iana.org/assignments/dhcpv6-parameters/dhcpv6-parameters.xhtml#dhcpv6-parameters-2.

Value	Description	Client ORO	Singleton Option	Reference
TBA1	OPTION_V6_DNS_RI	Yes	Yes	[ThisDocument]

9.2. DHCP Option

IANA is requested to assign the following new DHCP Option Code in the registry maintained in: https://www.iana.org/assignments/bootp-dhcp-parameters/bootp-dhcp-parameters.xhtml#options.

Tag	Name	Data Length	Meaning	Reference
TBA2	OPTION_V4_DNS_RI	N	DoT/DoH server authentication domain name	[ThisDocument]

9.3. RA Option

IANA is requested to assign the following new IPv6 Neighbor Discovery Option type in the "IPv6 Neighbor Discovery Option Formats" sub-registry under the "Internet Control Message Protocol version 6 (ICMPv6) Parameters" registry maintained in http://www.iana.org/assignments/icmpv6-parameters/icmpv6-parameters.xhtml#icmpv6-parameters-5.

Type	Description	Reference
TBA3	DNS Reference Identifier Option	[ThisDocument]

9.4. Service Name

IANA is requested to allocate the following service name from the registry available at: https://www.iana.org/assignments/service-names-port-numbers/service-names-port-numbers.xhtml.

Service Name:	doh
Port Number:	N/A
Transport Protocol(s):	TCP
Description:	DNS-over-HTTPS
Assignee:	IESG <iesg@ietf.org>
Contact:	IETF Chair <chair@ietf.org>
Reference:	[ThisDocument]

10. Acknowledgements

Many thanks to Christian Jacquenet for the review.

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