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S. Bortzmeyer  
AFNIC  
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**DNS privacy considerations  
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Abstract

This document describes the privacy issues associated with the use of the DNS by Internet users. It is intended to be mostly an analysis of the present situation, in the spirit of [section 8 of \[RFC6973\]](#) and it does not prescribe solutions.

Discussions of the document should take place on the DPRIVE working group mailing list [[dprive](#)].

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## [1.](#) Introduction

The Domain Name System is specified in [\[RFC1034\]](#) and [\[RFC1035\]](#). It is one of the most important infrastructure components of the Internet and one of the most often ignored or misunderstood. Almost every activity on the Internet starts with a DNS query (and often several). Its use has many privacy implications and we try to give here a comprehensive and accurate list.

Let us begin with a simplified reminder of how the DNS works. (REMOVE BEFORE PUBLICATION: We hope that the document [\[I-D.hoffman-dns-terminology\]](#) will be published as a RFC so most of this section could be replaced by a reference to it.) A client, the stub resolver, issues a DNS query to a server, the recursive resolver (also called caching resolver or full resolver or simply resolver recursive name server). Let's use the query "What are the AAAA records for `www.example.com`?" as an example. AAAA is the qtype (Query type), and `www.example.com` is the qname (Query Name). The recursive resolver will first query the root nameservers. In most cases, the root nameservers will send a referral. In this example, the referral will be to `.com` nameservers. The resolver repeats the query to one of the `.com` nameservers. The `.com` nameserver, in turn, will refer to the `example.com` nameservers. The `example.com`



nameserver will then return the answer. The root name servers, the name servers of .com and those of example.com are called authoritative name servers. It is important, when analyzing the privacy issues, to remember that the question asked to all these name servers is always the original question, not a derived question. Unlike what many "DNS for dummies" articles say, the question sent to the root name servers is "What are the AAAA records for www.example.com?", not "What are the name servers of .com?". By repeating the full question, instead of just the relevant part of the question to the next in line, the DNS provides more information than necessary to the nameserver.

Because the DNS uses caching heavily, not all questions are sent to the authoritative name servers. If the stub resolver, a few seconds later, asks to the recursive resolver "What are the SRV records of \_xmpp-server.\_tcp.example.com?", the recursive resolver will remember that it knows the name servers of example.com and will just query them, bypassing the root and .com. Because there is typically no caching in the stub resolver, the recursive resolver, unlike the authoritative servers, sees everything.

It should be noted that DNS recursive resolvers sometimes forward requests to bigger machines, with a larger and more shared cache, the forwarders (and the query hierarchy can be even deeper, with more than two levels of recursive resolvers). From the point of view of privacy, forwarders are like resolvers, except that the caching in the recursive resolvers before them decreases the amount of data they can see.

All this DNS traffic is today sent in clear (unencrypted), except a few cases when the IP traffic is protected, for instance in an IPsec VPN.

Today, almost all DNS queries are sent over UDP. This has practical consequences, when considering a possible privacy technique, encryption of the traffic: some encryption solutions are only designed for TCP, not UDP.

Another important point to keep in mind when analyzing the privacy issues of DNS is the mix of many sort of DNS requests received by a server. Let's assume the eavesdropper wants to know which Web page is viewed by an user. For a typical Web page displayed by the user, there are three sorts of DNS requests being issued:

Primary request: this is the domain name in the URL that the user typed or selected from a bookmark or choose by clicking on an hyperlink. Presumably, this is what is of interest for the eavesdropper.



Secondary requests: these are the additional requests performed by the user agent (here, the Web browser) without any direct involvement or knowledge of the user. For the Web, they are triggered by embedded content, CSS sheets, JavaScript code, embedded images, etc. In some cases, there can be dozens of domain names in different contexts on a single Web page.

Tertiary requests: these are the additional requests performed by the DNS system itself. For instance, if the answer to a query is a referral to a set of name servers, and the glue is not returned, the resolver will have to do tertiary requests to turn name servers' names into IP addresses. Similarly, even if glue records are returned, a careful recursive server will do tertiary requests to verify the IP addresses of those records.

It can be noted also that, in the case of a typical Web browser, more DNS requests are sent, for instance to prefetch resources that the user may query later, or when autocompleting the URL in the address bar (which obviously is a big privacy concern).

For privacy-related terms, we will use here the terminology of [\[RFC6973\]](#).

## **2. Risks**

This document focuses mostly on the study of privacy risks for the end-user (the one performing DNS requests). We consider the risks of pervasive surveillance ([\[RFC7258\]](#)) and also risks coming from a more focused surveillance. Privacy risks for the holder of a zone (the risk that someone gets the data) are discussed in [\[RFC5936\]](#). Non-privacy risks (such as cache poisoning) are out of scope.

### **[2.1.](#) The alleged public nature of DNS data**

It has long been claimed that "the data in the DNS is public". While this sentence makes sense for an Internet-wide lookup system, there are multiple facets to the data and metadata involved that deserve a more detailed look. First, access control lists and private namespaces notwithstanding, the DNS operates under the assumption that public facing authoritative name servers will respond to "usual" DNS queries for any zone they are authoritative for without further authentication or authorization of the client (resolver). Due to the lack of search capabilities, only a given qname will reveal the resource records associated with that name (or that name's non-existence). In other words: one needs to know what to ask for, in order to receive a response. The zone transfer qtype [\[RFC5936\]](#) is often blocked or restricted to authenticated/authorized access to enforce this difference (and maybe for other, more dubious reasons).



Another differentiation to be considered is between the DNS data itself and a particular transaction (i.e., a DNS name lookup). DNS data and the results of a DNS query are public, within the boundaries described above, and may not have any confidentiality requirements. However, the same is not true of a single transaction or sequence of transactions; that transaction is not/should not be public. A typical example from outside the DNS world is: the Web site of Alcoholics Anonymous is public; the fact that you visit it should not be.

## **2.2. Data in the DNS request**

The DNS request includes many fields but two of them seem particularly relevant for the privacy issues, the qname and the source IP address. "source IP address" is used in a loose sense of "source IP address + maybe source port", because the port is also in the request and can be used to sort out several users sharing an IP address (behind a CGN for instance).

The qname is the full name sent by the user. It gives information about what the user does ("What are the MX records of example.net?" means he probably wants to send email to someone at example.net, which may be a domain used by only a few persons and therefore very revealing about communication relationships). Some qnames are more sensitive than others. For instance, querying the A record of google-analytics.com reveals very little (everybody visits Web sites which use Google Analytics) but querying the A record of www.verybad.example where verybad.example is the domain of an illegal or very offensive organization may create more problems for the user. Also, sometimes, the qname embeds the software one uses, which could be a privacy issue. For instance, \_ldap.\_tcp.Default-First-Site-Name.\_sites.gc.\_msdcs.example.org. There are also some BitTorrent clients that query a SRV record for \_bittorrent-tracker.\_tcp.domain.example.

Another important thing about the privacy of the qname is the future usages. Today, the lack of privacy is an obstacle to putting potentially sensitive or personally identifiable data in the DNS. At the moment your DNS traffic might reveal that you are doing email but not with whom. If your MUA starts looking up PGP keys in the DNS [[I-D.wouters-dane-openpgp](#)] then privacy becomes a lot more important. And email is just an example; there would be other really interesting uses for a more privacy-friendly DNS.

For the communication between the stub resolver and the recursive resolver, the source IP address is the address of the user's machine. Therefore, all the issues and warnings about collection of IP addresses apply here. For the communication between the recursive





resolver and the authoritative name servers, the source IP address has a different meaning; it does not have the same status as the source address in a HTTP connection. It is now the IP address of the recursive resolver which, in a way "hides" the real user. However, hiding does not always work. Sometimes [\[I-D.vandergaast-edns-client-subnet\]](#) is used (see its privacy analysis in [\[denis-edns-client-subnet\]](#)). Sometimes the end user has a personal recursive resolver on her machine. In both cases, the IP address is as sensitive as it is for HTTP.

A note about IP addresses: there is currently no IETF document which describes in detail the privacy issues of IP addressing. In the meantime, the discussion here is intended to include both IPv4 and IPv6 source addresses. For a number of reasons their assignment and utilization characteristics are different, which may have implications for details of information leakage associated with the collection of source addresses. (For example, a specific IPv6 source address seen on the public Internet is less likely than an IPv4 address to originate behind a CGN or other NAT.) However, for both IPv4 and IPv6 addresses, it's important to note that source addresses are propagated with queries and comprise metadata about the host, user, or application that originated them.

### **[2.3.](#) Cache snooping**

The content of recursive resolvers' caches can reveal data about the clients using it (the privacy risks depend on the number of clients). This information can sometimes be examined by sending DNS queries with RD=0 to inspect cache content, particularly looking at the DNS TTLs. Since this also is a reconnaissance technique for subsequent cache poisoning attacks, some counter measures have already been developed and deployed.

### **[2.4.](#) On the wire**

DNS traffic can be seen by an eavesdropper like any other traffic. It is typically not encrypted. (DNSSEC, specified in [\[RFC4033\]](#) explicitly excludes confidentiality from its goals.) So, if an initiator starts a HTTPS communication with a recipient, while the HTTP traffic will be encrypted, the DNS exchange prior to it will not be. When other protocols will become more and more privacy-aware and secured against surveillance, the DNS risks to become "the weakest link" in privacy.

An important specificity of the DNS traffic is that it may take a different path than the communication between the initiator and the recipient. For instance, an eavesdropper may be unable to tap the wire between the initiator and the recipient but may have access to



the wire going to the recursive resolver, or to the authoritative name servers.

The best place to tap, from an eavesdropper's point of view, is clearly between the stub resolvers and the recursive resolvers, because traffic is not limited by DNS caching.

The attack surface between the stub resolver and the rest of the world can vary widely depending upon how the end user's computer is configured. By order of increasing attack surface:

The recursive resolver can be on the end user's computer. In (currently) a small number of cases, individuals may choose to operate their own DNS resolver on their local machine. In this case the attack surface for the connection between the stub resolver and the caching resolver is limited to that single machine.

The recursive resolver may be at the local network edge. For many/most enterprise networks and for some residential users the caching resolver may exist on a server at the edge of the local network. In this case the attack surface is the local network. Note that in large enterprise networks the DNS resolver may not be located at the edge of the local network but rather at the edge of the overall enterprise network. In this case the enterprise network could be thought of as similar to the IAP network referenced below.

The recursive resolver can be in the IAP (Internet Access Provider) premises. For most residential users and potentially other networks the typical case is for the end user's computer to be configured (typically automatically through DHCP) with the addresses of the DNS recursive resolvers at the IAP. The attack surface for on-the-wire attacks is therefore from the end user system across the local network and across the IAP network to the IAP's recursive resolvers.

The recursive resolver can be a public DNS service. Some machines may be configured to use public DNS resolvers such as those operated by Google Public DNS or OpenDNS. The end user may have configured their machine to use these DNS recursive resolvers themselves - or their IAP may have chosen to use the public DNS resolvers rather than operating their own resolvers. In this case the attack surface is the entire public Internet between the end user's connection and the public DNS service.

## **2.5. In the servers**

Using the terminology of [[RFC6973](#)], the DNS servers (recursive resolvers and authoritative servers) are enablers: they facilitate communication between an initiator and a recipient without being



directly in the communications path. As a result, they are often forgotten in risk analysis. But, to quote again [RFC6973], "Although [...] enablers may not generally be considered as attackers, they may all pose privacy threats (depending on the context) because they are able to observe, collect, process, and transfer privacy-relevant data." In [RFC6973] parlance, enablers become observers when they start collecting data.

Many programs exist to collect and analyze DNS data at the servers. From the "query log" of some programs like BIND, to tcpdump and more sophisticated programs like PacketQ [packetq] and DNSmezzo [dnsmezzo]. The organization managing the DNS server can use these data itself or it can be part of a surveillance program like PRISM [prism] and pass data to an outside observer.

Sometimes, these data are kept for a long time and/or distributed to third parties, for research purposes [ditl], for security analysis, or for surveillance tasks. Also, there are observation points in the network which gather DNS data and then make it accessible to third-parties for research or security purposes ("passive DNS [passive-dns]").

#### **2.5.1. In the recursive resolvers**

Recursive Resolvers see all the traffic since there is typically no caching before them. To summarize: your recursive resolver knows a lot about you. The resolver of a large IAP, or a large public resolver can collect data from many users. You may get an idea of the data collected by reading the privacy policy of a big public resolver [1].

#### **2.5.2. In the authoritative name servers**

Unlike what happens for recursive resolvers, observation capabilities of authoritative name servers are limited by caching; they see only the requests for which the answer was not in the cache. For aggregated statistics ("What is the percentage of LOC queries?"), this is sufficient; but it prevents an observer from seeing everything. Still, the authoritative name servers see a part of the traffic, and this subset may be sufficient to violate some privacy expectations.

Also, the end user has typically some legal/contractual link with the recursive resolver (he has chosen the IAP, or he has chosen to use a given public resolver), while having no control and perhaps no awareness of the role of the authoritative name servers and their observation abilities.



It is an interesting question whether the privacy issues are bigger in the root or in a large TLD. The root sees the traffic for all the TLDs (and the huge amount of traffic for non-existing TLDs), but a large TLDs has less caching before it.

As noted before, using a local resolver or a resolver close to the machine decreases the attack surface for an on-the-wire eavesdropper. But it may decrease privacy against an observer located on an authoritative name server. This authoritative name server will see the IP address of the end client, instead of the address of a big recursive resolver shared by many users.

This "protection", when using a large resolver with many clients, is no longer present if [[I-D.vandergaast-edns-client-subnet](#)] is used because, in this case, the authoritative name server sees the original IP address (or prefix, depending on the setup).

As of today, all the instances of one root name server, L-root, receive together around 20,000 queries per second. While most of it is junk (errors on the TLD name), it gives an idea of the amount of big data which pours into name servers.

Many domains, including TLDs, are partially hosted by third-party servers, sometimes in a different country. The contracts between the domain manager and these servers may or may not take privacy into account. Whatever the contract, the third-party hoster may be honest or not but, in any case, it will have to follow its local laws. It may be surprising for an end-user that requests to a given ccTLD may go to servers managed by organisations outside of the country.

Also, it seems (TODO: actual numbers requested) that there is a strong concentration of authoritative name servers among "popular" domains (such as the Alexa Top N list). With the control (or the ability to sniff the traffic) of a few name servers, you can gather a lot of information.

### **2.5.3. Rogue servers**

A rogue DHCP server, or a trusted DHCP server that has had its configuration altered by malicious parties, can direct you to a rogue recursive resolver. Most of the times, it seems to be done to divert traffic, by providing lies for some domain names. But it could be used just to capture the traffic and gather information about you. Same thing for malware like DNSChanger[dnschanger] which changes the recursive resolver in the machine's configuration, or with transparent DNS proxies in the network that will divert the traffic intended for a legitimate DNS server (for instance [[turkey-googledns](#)]).





### **3. Actual "attacks"**

A very quick examination of DNS traffic may lead to the false conclusion that extracting the needle from the haystack is difficult. "Interesting" primary DNS requests are mixed with useless (for the eavesdropper) second and tertiary requests (see the terminology in [Section 1](#)). But, in this time of "big data" processing, powerful techniques now exist to get from the raw data to what you're actually interested in.

Many research papers about malware detection use DNS traffic to detect "abnormal" behaviour that can be traced back to the activity of malware on infected machines. Yes, this research was done for the good but, technically, it is a privacy attack and it demonstrates the power of the observation of DNS traffic. See [[dns-footprint](#)], [[dagon-malware](#)] and [[darkreading-dns](#)].

Passive DNS systems [[passive-dns](#)] allow reconstruction of the data of sometimes an entire zone. It is used for many reasons, some good, some bad. It is an example of a privacy issue even when no source IP address is kept.

### **4. Legalities**

To our knowledge, there are no specific privacy laws for DNS data. Interpreting general privacy laws like [[data-protection-directive](#)] (European Union) in the context of DNS traffic data is not an easy task and it seems there is no court precedent here.

### **5. Security considerations**

This document is entirely about security, more precisely privacy. It just lays down the problem, it does not try to set requirements (with the choices and compromises they imply), much less to define solutions. A document on requirements for DNS privacy is [[I-D.hallambaker-dnse](#)]. Possible solutions to the issues described here are discussed in other documents (currently too many to be listed here).

### **6. Acknowledgments**

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### **7.3. URIs**

[1] <https://developers.google.com/speed/public-dns/privacy>

#### Author's Address

Stephane Bortzmeyer  
AFNIC  
1, rue Stephenson  
Montigny-le-Bretonneux 78180  
France

Phone: +33 1 39 30 83 46  
Email: [bortzmeyer+ietf@nic.fr](mailto:bortzmeyer+ietf@nic.fr)  
URI: <http://www.afnic.fr/>

