Internet Engineering Task Force (IETF)
Request for Comments: 7844
Category: Standards Track
ISSN: 2070-1721

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May 2016

Anonymity Profiles for DHCP Clients

Abstract

Some DHCP options carry unique identifiers. These identifiers can enable device tracking even if the device administrator takes care of randomizing other potential identifications like link-layer addresses or IPv6 addresses. The anonymity profiles are designed for clients that wish to remain anonymous to the visited network. The profiles provide guidelines on the composition of DHCP or DHCPv6 messages, designed to minimize disclosure of identifying information.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc7844.

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1. Introduction

There have been reports of systems that would monitor the wireless connections of passengers at Canadian airports [CNBC]. We can assume that these are either fragments or trial runs of a wider system that would attempt to monitor Internet users as they roam through wireless access points and other temporary network attachments. We can also assume that privacy-conscious users will attempt to evade this monitoring -- for example, by ensuring that low-level identifiers such as link-layer addresses are "randomized", so that the devices do not broadcast the same unique identifier in every location that they visit.

Of course, link-layer MAC (Media Access Control) addresses are not the only way to identify a device. As soon as it connects to a remote network, the device may use DHCP and DHCPv6 to obtain network parameters. The analysis of DHCP and DHCPv6 options shows that parameters of these protocols can reveal identifiers of the device, negating the benefits of link-layer address randomization. This is documented in detail in [RFC7819] and [RFC7824]. The natural reaction is to restrict the number and values of such parameters in order to minimize disclosure.

In the absence of a common standard, different system developers are likely to implement this minimization of disclosure in different ways. Monitoring entities could then use the differences to identify the software version running on the device. The proposed anonymity profiles provide a common standard that minimizes information disclosure, including the disclosure of implementation identifiers.

1.1. Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Application Domain

Mobile nodes can be tracked using multiple identifiers, the most prominent being link-layer addresses, a.k.a. MAC addresses. For example, when devices use Wi-Fi connectivity, they place the MAC address in the header of all the packets that they transmit. Standard implementations of Wi-Fi use unique 48-bit link-layer addresses, assigned to the devices according to procedures defined by IEEE 802. Even when the Wi-Fi packets are encrypted, the portion of the header containing the addresses will be sent in cleartext. Tracking devices can "listen to the airwaves" to find out what devices are transmitting near them.

We can easily imagine that the MAC addresses can be correlated with other data, e.g., cleartext names and cookies, to build a registry linking MAC addresses to the identity of devices' owners. Once that correlation is done, tracking the MAC address is sufficient to track individual people, even when all application data sent from the devices is encrypted. Link-layer addresses can also be correlated with IP addresses of devices, negating the potential privacy benefits of IPv6 "privacy" addresses. Privacy advocates have reasons to be concerned.

The obvious solution is to "randomize" the MAC address. Before connecting to a particular network, the device replaces the MAC address with a randomly drawn 48-bit value. Link-layer address randomization was successfully tried at the IETF meeting in Honolulu in November 2014 [IETFMACRandom] and in subsequent meetings [IETFTrialsAndMore]; it is studied in the IEEE 802 EC Privacy Recommendation Study Group [IEEE802PRSG]. However, we have to consider the linkage between link-layer addresses, DHCP identifiers, and IP addresses.

2.1. MAC Address Randomization Hypotheses

There is not yet an established standard for randomizing link-layer addresses. Various prototypes have tried different strategies, such as:

Per connection: Configure a random link-layer address at the time of connecting to a network, e.g., to a specific Wi-Fi SSID (Service Set Identifier), and keep it for the duration of the connection.

Per network: Same as "per connection", but always use the same link-layer address for the same network -- different, of course, from the addresses used in other networks.

Time interval: Change the link-layer address at regular time intervals.

In practice, there are many reasons to keep the link-layer address constant for the duration of a link-layer connection, as in the "per connection" or "per network" variants. In Wi-Fi networks, changing the link-layer address requires dropping the existing Wi-Fi connection and then re-establishing it, which implies repeating the connection process and associated procedures. The IP addresses will change, which means that all required TCP connections will have to be re-established. If the network access is provided through a NAT, changing IP addresses also means that the NAT traversal procedures will have to be restarted. This means a lot of disruption. At the same time, an observer on the network will easily notice that a

station left, another came in just after that, and the new one appears to be communicating with the same set of IP addresses as the old one. This provides for easy correlation.

The anonymity profiles pretty much assume that the link-layer address randomization follows the "per connection" or "per network" strategies, or a variant of the "time interval" strategy in which the interval has about the same duration as the average connection.

2.2. MAC Address Randomization and DHCP

From a privacy point of view, it is clear that the link-layer address, IP address, and DHCP identifier shall evolve in synchrony. For example, if the link-layer address changes and the DHCP identifier stays constant, then it is really easy to correlate old and new link-layer addresses, either by listening to DHCP traffic or by observing that the IP address remains constant, since it is tied to the DHCP identifier. Conversely, if the DHCP identifier changes but the link-layer address remains constant, the old and new identifiers and addresses can be correlated by listening to L2 traffic. The procedures documented in the following sections construct DHCP identifiers from the current link-layer address, automatically providing for this synchronization.

The proposed anonymity profiles solve this synchronization issue by deriving most identifiers from the link-layer address and by generally making sure that DHCP parameter values do not remain constant after an address change.

2.3. Radio Fingerprinting

MAC address randomization solves the trivial monitoring problem in which someone just uses a Wi-Fi scanner and records the MAC addresses seen on the air. DHCP anonymity solves the more elaborate scenario in which someone monitors link-layer addresses and identities used in DHCP at the access point or DHCP server. But these are not the only ways to track a mobile device.

Radio fingerprinting is a process that identifies a radio transmitter by the unique "fingerprint" of its signal transmission, i.e., the tiny differences caused by minute imperfections of the radio transmission hardware. This can be applied to diverse types of radios, including Wi-Fi as described, for example, in [WiFiRadioFingerprinting]. No amount of link-layer address randomization will protect against such techniques. Protections may exist, but they are outside the scope of the present document.

On the other hand, we should not renounce randomization just because radio fingerprinting exists. The radio fingerprinting techniques are harder to deploy than just recording link-layer addresses with a scanner. Such techniques can only track devices for which the fingerprints are known and thus have a narrower scope of application than mass monitoring of addresses and DHCP parameters.

2.4. Operating System Fingerprinting

When a standard like DHCP allows for multiple options, different implementers will make different choices for the options that they support or the values they choose for the options. Conversely, monitoring the options and values present in DHCP messages reveals these differences and allows for "operating system fingerprinting", i.e., finding the type and version of software that a particular device is running. Finding these versions provides some information about the device's identity and thus goes against the goal of anonymity.

The design of the anonymity profiles attempts to minimize the number of options and the choice of values, in order to reduce the possibilities of operating system fingerprinting.

2.5. No Anonymity Profile Identification

Reviewers of the anonymity profiles have sometimes suggested adding an option to explicitly identify the profiles as "using the anonymity option". One suggestion is that the client tell the server about its desire to remain anonymous, so that a willing server could cooperate and protect the client's privacy. Another possibility would be to use a specific privacy-oriented construct, such as, for example, a new type of DHCP Unique Identifier (DUID) for a temporary DUID that would be changing over time.

This is not workable in a large number of cases, as it is possible that the network operator (or other entities that have access to the operator's network) might be actively participating in surveillance and anti-privacy, willingly or not. Declaring a preference for anonymity is a bit like walking around with a Guy Fawkes mask. (See [GuyFawkesMask] for an explanation of this usage.) When anonymity is required, it is generally not a good idea to stick out of the crowd. Simply revealing the desire for privacy could cause the attacker to react by triggering additional surveillance or monitoring mechanisms. Therefore, we feel that it is preferable to not disclose one's desire for privacy.

This preference leads to some important implications. In particular, we make an effort to make the mitigation techniques difficult to distinguish from regular client behaviors, if at all possible.

2.6. Using the Anonymity Profiles

There are downsides to randomizing link-layer addresses and DHCP identifiers. By definition, randomization will break management procedures that rely on tracking link-layer addresses. Even if this is not too much of a concern, we have to be worried about the frequency of link-layer address randomization. Suppose, for example, that many devices would get new random link-layer addresses at short intervals, maybe every few minutes. This would generate new DHCP requests in rapid succession, with a high risk of exhausting DHCPv4 address pools. Even with IPv6, there would still be a risk of increased neighbor discovery traffic and bloating of various address tables. Implementers will have to be cautious when programming devices to use randomized MAC addresses. They will have to carefully choose the frequency with which such addresses will be renewed.

This document only provides guidelines for using DHCP when clients care about privacy. We assume that the request for anonymity is materialized by the assignment of a randomized link-layer address to the network interface. Once that decision is made, the following guidelines will avoid leakage of identity in DHCP parameters or in assigned addresses.

There may be rare situations where the clients want to remain anonymous to attackers but not to the DHCP server. These clients should still use link-layer address randomization to hide from observers, as well as some form of encrypted communication to the DHCP server. This scenario is out of scope for this document.

To preserve anonymity, the clients need to not use stable values for the client identifiers. This is clearly a trade-off, because a stable client identifier guarantees that the client will receive consistent parameters over time. An example is given in [RFC7618], where the client identifier is used to guarantee that the same client will always get the same combination of IP address and port range. Static clients benefit most from stable parameters and often can already be identified by physical-connection-layer parameters. These static clients will normally not use the anonymity profiles. Mobile clients, in contrast, have the option of using the anonymity profiles in conjunction with [RFC7618] if they are more concerned with privacy protection than with stable parameters.

2.7. What about privacy for DHCP servers?

This document only provides recommendations for DHCP clients. The main targets are DHCP clients used in mobile devices. Such devices are tempting targets for various monitoring systems, so there is an urgent need to provide them with a simple anonymity solution. We can argue that some mobile devices embed DHCP servers and that providing solutions for such devices is also quite important. Two plausible examples would be a DHCP server for a car network and a DHCP server for a mobile hot spot. However, mobile servers get a lot of privacy protection through the use of access control and link-layer encryption. Servers may disclose information to clients through DHCP, but they normally only do that to clients that have passed the link-layer access control and have been authorized to use the network services. This arguably makes solving the server problem less urgent than solving the client problem.

Server privacy issues are presented in [RFC7819] and [RFC7824]. Mitigation of these issues is left for further study.

3. Anonymity Profile for DHCPv4

Clients using the DHCPv4 anonymity profile limit the disclosure of information by controlling the header parameters and by limiting the number and values of options. The number of options depends on the specific DHCP message:

DHCPDISCOVER: The anonymized DHCPDISCOVER messages MUST contain the Message Type option, MAY contain the Client Identifier option, and MAY contain the Parameter Request List option. It SHOULD NOT contain any other option.

DHCPREQUEST: The anonymized DHCPREQUEST messages MUST contain the Message Type option, MAY contain the Client Identifier option, and MAY contain the Parameter Request List option. If the message is in response to a DHCPOFFER, it MUST contain the corresponding Server Identifier option and the Requested IP address option. If the message is not in response to a DHCPOFFER, it MAY contain a Requested IP address option as explained in Section 3.3. It SHOULD NOT contain any other option.

DHCPDECLINE: The anonymized DHCPDECLINE messages MUST contain the Message Type option, the Server Identifier option, and the Requested IP address option; and MAY contain the Client Identifier option.

DHCPRELEASE: The anonymized DHCPRELEASE messages MUST contain the Message Type option and the Server Identifier option, and MAY contain the Client Identifier option.

DHCPINFORM: The anonymized DHCPINFORM messages MUST contain the Message Type option, MAY contain the Client Identifier option, and MAY contain the Parameter Request List option. It SHOULD NOT contain any other option.

Header fields and option values SHOULD be set in accordance with the DHCP specification, but some header fields and option values SHOULD be constructed per the following guidelines.

The inclusion of the Host Name and Fully Qualified Domain Name (FQDN) options in DHCPDISCOVER, DHCPREQUEST, or DHCPINFORM messages is discussed in Sections 3.7 and 3.8.

3.1. Avoiding Fingerprinting

There are many choices for implementing DHCPv4 messages. Clients can choose to transmit a specific set of options, pick a particular encoding for these options, and transmit options in different orders. These choices can be used to fingerprint the client.

The following sections provide guidance on the encoding of options and fields within the packets. However, this guidance alone may not be sufficient to prevent fingerprinting from revealing the device type, the vendor name, or the OS type and specific version. Fingerprinting may also reveal whether the client is using the anonymity profile.

The client intending to protect its privacy SHOULD limit the subset of options sent in messages to the subset listed in the remaining subsections.

The client intending to protect its privacy SHOULD randomize the ordering of options before sending any DHCPv4 message. If this random ordering cannot be implemented, the client MAY order the options by option code number (lowest to highest).

3.2. Client IP Address Field

Four octets in the header of the DHCP messages carry the "Client IP address" (ciaddr) as defined in [RFC2131]. In DHCP, this field is used by the clients to indicate the address that they used previously, so that as much as possible the server can allocate the same address to them.

There are very few privacy implications related to sending this address in the DHCP messages, except in the case of connecting to a different network than the last network connected to previously. If the DHCP client somehow repeated the address used in a previous network attachment, monitoring services might use the information to tie the two network locations. DHCP clients SHOULD ensure that the field is cleared when they know that the network attachment has changed, particularly if the link-layer address is reset by a device's administrator.

The clients using the anonymity profile MUST NOT include in the message a Client IP address that has been obtained with a different link-layer address.

3.3. Requested IP Address Option

The Requested IP address option is defined in [RFC2132] with code 50. It allows the client to request that a particular IP address be assigned. This option is mandatory in some protocol messages per [RFC2131] -- for example, when a client selects an address offered by a server. However, this option is not mandatory in the DHCPDISCOVER message. It is simply a convenience -- an attempt to regain the same IP address that was used in a previous connection. Doing so entails the risk of disclosing an IP address used by the client at a previous location or with a different link-layer address. This risk exists for all forms of IP addresses, public or private, as some private addresses may be used in a wide scope, e.g., when an Internet Service Provider is using NAT.

When using the anonymity profile, clients SHOULD NOT use the Requested IP address option in DHCPDISCOVER messages. They MUST use the option when mandated by DHCP -- for example, in DHCPREQUEST messages.

There are scenarios in which a client connecting to a network remembers a previously allocated address, i.e., when it is in the INIT-REBOOT state. In that state, any client that is concerned with privacy SHOULD perform a complete four-way handshake, starting with a DHCPDISCOVER, to obtain a new address lease. If the client can ascertain that this is exactly the same network to which it was previously connected, and if the link-layer address did not change, the client MAY issue a DHCPREQUEST to try to reclaim the current address.

3.4. Client Hardware Address Field

Sixteen octets in the header of the DHCP messages carry the "Client hardware address" (chaddr) as defined in [RFC2131]. The presence of this address is necessary for the proper operation of the DHCP service.

Hardware addresses, called "link-layer addresses" in many RFCs, can be used to uniquely identify a device, especially if they follow the IEEE 802 recommendations. If the hardware address is reset to a new randomized value, the DHCP client SHOULD use the new randomized value in the DHCP messages.

3.5. Client Identifier Option

The Client Identifier option is defined in [RFC2132] with option code 61. It is discussed in detail in [RFC4361]. The purpose of the Client Identifier option is to identify the client in a manner independent of the link-layer address. This is particularly useful if the DHCP server is expected to assign the same address to the client after a network attachment is swapped and the link-layer address changes. It is also useful when the same node issues requests through several interfaces and expects the DHCP server to provide consistent configuration data over multiple interfaces.

The considerations for hardware independence and strong client identity have an adverse effect on the privacy of mobile clients, because the hardware-independent unique identifier obviously enables very efficient tracking of the clients' movements. One option would be to not transmit this option at all, but this may affect interoperability and will definitely mark the client as requesting anonymity, exposing it to the risks mentioned in Section 2.5.

The recommendations in [RFC4361] are very strong, stating, for example, that "DHCPv4 clients MUST NOT use client identifiers based solely on layer two addresses that are hard-wired to the layer two device (e.g., the Ethernet MAC address)." These strong recommendations are in fact a trade-off between ease of management and privacy, and the trade-off should depend on the circumstances.

In contradiction to [RFC4361], when using the anonymity profile, DHCP clients MUST use client identifiers based solely on the link-layer address that will be used in the underlying connection. This will ensure that the DHCP client identifier does not leak any information that is not already available to entities monitoring the network connection. It will also ensure that a strategy of randomizing the link-layer address will not be nullified by the Client Identifier option.

There are usages of DHCP where the underlying connection is a point-to-point link, in which case there is no link-layer address available to construct a non-revealing identifier. If anonymity is desired in such networks, the client SHOULD pick a random identifier that is highly likely to be unique to the current link, using, for example, a combination of a local secret and an identifier of the connection. The algorithm for combining secrets and identifiers, as described in Section 5 of [RFC7217], solves a similar problem. The criteria for the generation of random numbers are stated in [RFC4086].

3.6. Parameter Request List Option

The Parameter Request List (PRL) option is defined in [RFC2132] with option code 55. It lists the parameters requested from the server by the client. Different implementations request different parameters. [RFC2132] specifies that "the client MAY list the options in order of preference." In practice, this means that different client implementations will request different parameters, in different orders.

The choice of option numbers and the specific ordering of option numbers in the PRL can be used to fingerprint the client. This may not reveal the identity of a client but may provide additional information such as the device type, the vendor name, or the OS type and specific version.

The client intending to protect its privacy SHOULD only request a minimal number of options in the PRL and SHOULD also randomly shuffle the ordering of option codes in the PRL. If this random ordering cannot be implemented, the client MAY order the option codes in the PRL by option code number (lowest to highest).

3.7. Host Name Option

The Host Name option is defined in [RFC2132] with option code 12. Depending on implementations, the option value can carry either an FQDN such as "node1984.example.com" or a simple host name such as "node1984". The host name is commonly used by the DHCP server to identify the host and also to automatically update the address of the host in local name services.

FQDNs are obviously unique identifiers, but even simple host names can provide a significant amount of information on the identity of the device. They are typically chosen to be unique in the context where the device is most often used. In a context that contains a substantial number of devices, e.g., in a large company or a big university, the host name will be a pretty good identifier of the

device, due to the specificity required to ensure uniqueness. Monitoring services could use that information in conjunction with traffic analysis and quickly derive the identity of the device's owner.

When using the anonymity profile, DHCP clients SHOULD NOT send the Host Name option. If they choose to send the option, DHCP clients MUST always send a non-qualified host name instead of an FQDN and MUST obfuscate the host name value.

There are many ways to obfuscate a host name. The construction rules SHOULD guarantee that a different host name is generated each time the link-layer address changes and that the obfuscated host name will not reveal the underlying link-layer address. The construction SHOULD generate names that are unique enough to minimize collisions in the local link. Clients MAY use the following algorithm: compute a secure hash of a local secret and of the link-layer address that will be used in the underlying connection, and then use the hexadecimal representation of the first 6 octets of the hash as the obfuscated host name.

The algorithm described in the previous paragraph generates an easily recognizable pattern. There is a potential downside to having such a specific name pattern for hosts that require anonymity (the "sticking out of the crowd" principle), as explained in Section 2.5. For this reason, the above algorithm is just a suggestion.

3.8. Client FQDN Option

The Client FQDN option is defined in [RFC4702] with option code 81. This option allows the DHCP clients to advertise to the DHCP server their FQDN, such as "mobile.example.com". This would allow the DHCP server to update in the DNS the PTR record for the IP address allocated to the client. Depending on circumstances, either the DHCP client or the DHCP server could update in the DNS the A record for the FQDN of the client.

Obviously, this option uniquely identifies the client, exposing it to the DHCP server or to anyone listening to DHCP traffic. In fact, if the DNS record is updated, the location of the client becomes visible to anyone with DNS lookup capabilities.

When using the anonymity profile, DHCP clients SHOULD NOT include the Client FQDN option in their DHCP requests. Alternatively, they MAY include a special-purpose FQDN using the same host name as in the Host Name option, with a suffix matching the connection-specific DNS suffix being advertised by that DHCP server. Having a name in the

DNS allows working with legacy systems that require one to be there, e.g., by verifying that a forward and reverse lookup succeeds with the same result.

3.9. UUID/GUID-Based Client Machine Identifier Option

The UUID/GUID-based (where "UUID" means "Universally Unique Identifier" and "GUID" means "Globally Unique Identifier") Client Machine Identifier option is defined in [RFC4578] with option code 97. This option is part of a set of options for the Intel Preboot eXecution Environment (PXE). The purpose of the PXE system is to perform management functions on a device before its main OS is operational. The Client Machine Identifier carries a 16-octet GUID that uniquely identifies the device.

The PXE system is clearly designed for devices operating in a controlled environment. The main usage of the PXE system is to install a new version of the operating system through a high-speed Ethernet connection. The process is typically controlled from the user interface during the boot process. Common sense seems to dictate that getting a new operating system from an unauthenticated server at an untrusted location is a really bad idea and that even if the option was available users would not activate it. In any case, the option is only used in the "pre-boot" environment, and there is no reason to use it once the system is up and running. Nodes visiting untrusted networks MUST NOT send or use the PXE options.

3.10. User and Vendor Class DHCP Options

Vendor-identifying options are defined in [RFC2132] and [RFC3925]. When using the anonymity profile, DHCPv4 clients SHOULD NOT use the Vendor-Specific Information option (code 43), the Vendor Class Identifier option (code 60), the V-I Vendor Class option (code 124), or the V-I Vendor-Specific Information option (code 125), as these options potentially reveal identifying information.

4. Anonymity Profile for DHCPv6

DHCPv6 is typically used by clients in one of two scenarios: stateful or stateless configuration. In the stateful scenario, clients use a combination of Solicit, Request, Confirm, Renew, Rebind, Release, and Decline messages to obtain addresses and manage these addresses.

In the stateless scenario, clients configure addresses using a combination of client-managed identifiers and router-advertised prefixes, without involving the DHCPv6 services. Different ways of constructing these prefixes have different implications on privacy, which are discussed in [DEFAULT-IIDs] and [RFC7721]. In the stateless scenario, clients use DHCPv6 to obtain network configuration parameters, through the Information-request message.

The choice between the stateful and stateless scenarios depends on flag and prefix options published by the Router Advertisement messages of local routers, as specified in [RFC4861]. When these options enable stateless address configuration, hosts using the anonymity profile SHOULD use stateless address configuration instead of stateful address configuration, because stateless configuration requires fewer information disclosures than stateful configuration.

When using the anonymity profile, DHCPv6 clients carefully select DHCPv6 options used in the various messages that they send. The list of options that are mandatory or optional for each message is specified in [RFC3315]. Some of these options have specific implications on anonymity. The following sections provide guidance on the choice of option values when using the anonymity profile.

4.1. Avoiding Fingerprinting

There are many choices for implementing DHCPv6 messages. As explained in Section 3.1, these choices can be used to fingerprint the client.

The following sections provide guidance on the encoding of options. However, this guidance alone may not be sufficient to prevent fingerprinting from revealing the device type, the vendor name, or the OS type and specific version. Fingerprinting may also reveal whether the client is using the anonymity profile.

The client intending to protect its privacy SHOULD limit the subset of options sent in messages to the subset listed in the following sections.

The client intending to protect its privacy SHOULD randomize the ordering of options before sending any DHCPv6 message. If this random ordering cannot be implemented, the client MAY order the options by option code number (lowest to highest).

4.2. Do not send Confirm messages, unless really sure about the location

[RFC3315] requires clients to send a Confirm message when they attach to a new link to verify whether the addressing and configuration information they previously received is still valid. This requirement was relaxed in [DHCPv6bis]. When these clients send Confirm messages, they include any Identity Associations (IAs) assigned to the interface that may have moved to a new link, along with the addresses associated with those IAs. By examining the addresses in the Confirm message, an attacker can trivially identify the previous point(s) of attachment.

Clients interested in protecting their privacy SHOULD NOT send Confirm messages and instead SHOULD directly try to acquire addresses on the new link. However, not sending Confirm messages can result in connectivity hiatus in some scenarios, e.g., roaming between two access points in the same wireless network. DHCPv6 clients that can verify that the previous link and the current link are part of the same network MAY send Confirm messages while still protecting their privacy. Such link identification should happen before DHCPv6 is used, and thus it cannot depend on the DHCPv6 information used in [RFC6059]. In practice, the most reliable detection of network attachment is through link-layer security, e.g., [IEEE8021X].

4.3. Client Identifier DHCPv6 Option

The DHCPv6 Client Identifier option is defined in [RFC3315] with option code 1. The purpose of the Client Identifier option is to identify the client to the server. The content of the option is a DHCP Unique Identifier (DUID). One of the primary privacy concerns is that a client is disclosing a stable identifier (the DUID) that can be used for tracking and profiling. Three DUID formats are specified in [RFC3315]: link-layer address plus time (DUID-LLT), Vendor-assigned unique ID based on Enterprise Number, and link-layer address. A fourth type, DUID-UUID, is defined in [RFC6355].

When using the anonymity profile in conjunction with randomized link-layer addresses, DHCPv6 clients MUST use DUID format number 3 -- link-layer address. The value of the link-layer address should be the value currently assigned to the interface.

When using the anonymity profile without the benefit of randomized link-layer addresses, clients that want to protect their privacy SHOULD generate a new randomized DUID-LLT every time they attach to a new link or detect a possible link change event. Syntactically, this identifier will conform to [RFC3315], but its content is meaningless. The exact details are left up to implementers, but there are several

factors that should be taken into consideration. The DUID type SHOULD be set to 1 (DUID-LLT). Hardware type SHOULD be set appropriately to the hardware type in question. The link address embedded in the LLT SHOULD be set to a randomized value. Time SHOULD be set to a random timestamp from the previous year. Time MAY be set to current time, but this will reveal the fact that the DUID is newly generated and thus could provide information for device fingerprinting. The criteria for generating highly unique random numbers are listed in [RFC4086].

4.3.1. Anonymous Information-request

According to [RFC3315], a DHCPv6 client includes its client identifier in most of the messages it sends. There is one exception, however: the client is allowed to omit its client identifier when sending Information-request messages.

When using stateless DHCPv6, clients wanting to protect their privacy SHOULD NOT include client identifiers in their Information-request messages. This will prevent the server from specifying client-specific options if it is configured to do so, but the need for anonymity precludes such options anyway.

4.4. Server Identifier Option

When using the anonymity profile, DHCPv6 clients SHOULD use the Server Identifier option (code 2) as specified in [RFC3315]. Clients MUST only include server identifier values that were received with the current link-layer address, because the reuse of old values discloses information that can be used to identify the client.

4.5. Address Assignment Options

When using the anonymity profile, DHCPv6 clients might have to use Solicit or Request messages to obtain IPv6 addresses through the DHCPv6 server. In DHCPv6, the collection of addresses assigned to a client is identified by an IA. Clients interested in privacy SHOULD request addresses using the IA for the Non-temporary Addresses option (IA_NA, code 3) [RFC3315].

The IA_NA option includes an IAID parameter that identifies a unique IA for the interface for which the address is requested. Clients interested in protecting their privacy MUST ensure that the IAID does not enable client identification. They also need to conform to the requirement of [RFC3315] that the IAID for that IA MUST be consistent across restarts of the DHCPv6 client. We interpret that as requiring that the IAID MUST be constant for the association, as long as the link-layer address remains constant.

Clients MAY meet the privacy, uniqueness, and stability requirements of the IAID by constructing it as the combination of 1 octet encoding the interface number in the system, and the first 3 octets of the link-layer address.

The clients MAY use the IA Address option (code 5) [RFC3315] but need to balance the potential advantage of "address continuity" versus the potential risk of "previous address disclosure". A potential solution is to remove all stored addresses when a link-layer address changes and to only use the IA Address option with addresses that have been explicitly assigned through the current link-layer address.

4.5.1. Obtain Temporary Addresses

[RFC3315] defines a special container (IA_TA, code 4) for requesting temporary addresses. This is a good mechanism in principle, but there are a number of issues associated with it. First, this is not a widely used feature, so clients depending solely on temporary addresses may lock themselves out of service. Secondly, [RFC3315] does not specify any lifetime or lease length for temporary addresses. Therefore, support for renewing temporary addresses may vary between client implementations, including no support at all. Finally, by requesting temporary addresses, a client reveals its desire for privacy and potentially risks countermeasures as described in Section 2.5.

Because of these issues, clients interested in their privacy SHOULD NOT use IA_TA.

The addresses obtained according to Section 4.5 are meant to be non-temporary, but the anonymity profile uses them as temporary, and they will be discarded when the link-layer address is changed. They thus meet most of the use cases of the temporary addresses defined in [RFC4941]. Clients interested in their privacy should not publish their IPv6 addresses in the DNS or otherwise associate them with name services, and thus do not normally need two classes of addresses -- one public, one temporary.

The use of mechanisms to allocate several IPv6 addresses to a client while preserving privacy is left for further study.

4.5.2. Prefix Delegation

The use of DHCPv6 address assignment option for Prefix Delegation (PD) is defined in [RFC3633]. Because current host OS implementations do not typically request prefixes, clients that wish to use DHCPv6 PD -- just like clients that wish to use any DHCP or DHCPv6 option that is not currently widely used -- should recognize that doing so will serve as a form of fingerprinting, unless or until the use of DHCPv6 PD by clients becomes more widespread.

The anonymity properties of DHCPv6 PD, which uses IA_PD IAs, are similar to those of DHCPv6 address assignment using IA_NA IAs. The IAID could potentially be used to identify the client, and a prefix hint sent in the IA_PD Prefix option could be used to track the client's previous location. Clients that desire anonymity and never request more than one prefix SHOULD set the IAID value to zero, as authorized in Section 6 of [RFC3633], and SHOULD NOT document any previously assigned prefix in the IA_PD Prefix option.

4.6. Option Request Option

The Option Request Option (ORO) is defined in [RFC3315] with option code 6. It specifies the options that the client is requesting from the server. The choice of requested options and the order of encoding of these options in the ORO can be used to fingerprint the client.

The client intending to protect its privacy SHOULD only request a minimal subset of options and SHOULD randomly shuffle the ordering of option codes in the ORO. If this random ordering cannot be implemented, the client MAY order the option codes in the ORO by option code number (lowest to highest).

4.6.1. Previous Option Values

According to [RFC3315], the client that includes an ORO in a Solicit or Request message MAY additionally include instances of those options that are identified in the ORO, with data values as hints to the server about parameter values the client would like to have returned.

When using the anonymity profile, clients SHOULD NOT include such instances of options, because old values might be used to identify the client.

4.7. Authentication Option

The purpose of the Authentication option (code 11) [RFC3315] is to authenticate the identity of clients and servers and the contents of DHCPv6 messages. As such, the option can be used to identify the client, so it is incompatible with the stated goal of "client anonymity". DHCPv6 clients that use the anonymity profile SHOULD NOT use the Authentication option. They MAY use it if they recognize that they are operating in a trusted environment, e.g., in a workplace network.

4.8. User and Vendor Class DHCPv6 Options

When using the anonymity profile, DHCPv6 clients SHOULD NOT use the User Class option (code 15) or the Vendor Class option (code 16) [RFC3315], as these options potentially reveal identifying information.

4.9. Client FQDN DHCPv6 Option

The DHCPv6 Client FQDN option is defined in [RFC4704] with option code 39. This option allows the DHCPv6 clients to advertise to the DHCPv6 server their FQDN, such as "mobile.example.com". When using the anonymity profile, DHCPv6 clients SHOULD NOT include the Client FQDN option in their DHCPv6 messages, because it identifies the client. As explained in Section 3.8, they MAY use a local-only FQDN by combining a host name derived from the link-layer address and a suffix advertised by the local DHCPv6 server.

5. Operational Considerations

The anonymity profiles have the effect of hiding the client identity from the DHCP server. This is not always desirable. Some DHCP servers provide facilities like publishing names and addresses in the DNS, or ensuring that returning clients get reassigned the same address.

Clients using an anonymity profile may be consuming more resources. For example, when a client changes its link-layer address and requests a new IP address, the old IP address is still marked as leased by the server.

Some DHCP servers will only give addresses to pre-registered MAC addresses, forcing clients to choose between remaining anonymous and obtaining connectivity.

Implementers SHOULD provide a way for clients to control when the anonymity profiles are used and when standard behavior is preferred.

Implementers MAY implement this control by tying the use of the anonymity profiles to that of link-layer address randomization.

6. Security Considerations

The use of the anonymity profiles does not change the security considerations of the DHCPv4 or DHCPv6 protocols [RFC2131] [RFC3315].

7. References

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Acknowledgments

The inspiration for this document came from discussions in the Perpass mailing list. Several people provided feedback on this document, notably Noel Anderson, Brian Carpenter, Lorenzo Colitti, Stephen Farrell, Nick Grifka, Tushar Gupta, Brian Haberman, Gabriel Montenegro, Marcin Siodelski, Dave Thaler, Bernie Volz, and Jun Wu.

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