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IPv6 Address Usage Recommendations
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Abstract

This document analyzes the security and privacy implications of IPv6 addresses based on a number of properties such as address scope, stability, and usage type. It analyzes what properties are desirable for some popular scenarios, and provides advice regarding the configuration and usage of such addresses.

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1. Introduction

IPv6 hosts typically configure a number of IPv6 addresses, which may differ in multiple aspects, such as address scope and stability (e.g. stable addresses vs. temporary addresses). For example, a host may configure one stable and one temporary address per each autoconfiguration prefix advertised on the local network. The addresses to be configured typically depend on local system policy configuration, with the aforementioned policy being static and irrespective of the network the host attaches to.

There are three parameters that affect the security and privacy properties of an address:

- o Scope

- o Stability
- o Usage type (client-like "outgoing connections" vs. server-like "incoming connections")

[Section 5.1](#), [Section 5.2](#), and [Section 5.3](#) discuss the security and privacy implications (and associated tradeoffs) of the scope, stability and usage type properties of IPv6 addresses, respectively.

2. Terminology

This document employs the definitions of "public address", "stable address", and "temporary address" from [Section 2 of \[RFC7721\]](#).

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 [RFC 2119 \[RFC2119\]](#).

3. Background

Predictable IPv6 addresses result in a number of security and privacy implications. For example, [[Barnes2012](#)] discusses how patterns in network prefixes can be leveraged for IPv6 address scanning. On the other hand, [[RFC7707](#)], [[RFC7721](#)] and [[RFC7217](#)] discuss the security and privacy implications of predictable IPv6 Interface Identifiers (IIDs).

Given the aforementioned previous work in this area, and the formal specification update produced by [[RFC8064](#)], we expect (and assume in the rest of this document) that implementations have replaced any schemes that produce predictable addresses with alternative schemes that avoid such patterns (e.g., [RFC7217](#) in replacement of the traditional SLAAC addresses that embed link-layer addresses).

4. Problem Statement

Applications use system API's to select the IPv6 addresses that will be used for incoming and outgoing connections. This choices have consequences in terms of privacy, security, stability and performance.

Default Address Selection for IPv6 is specified in [[RFC6724](#)]. The selection starts with a set of potential destination addresses, such as returned by `getaddrinfo()`, and the set of potential source addresses currently configured for the selected interfaces. For each potential destination address, the algorithm will select the source address that provides the best route to the destination, while choosing the appropriate scope and preferring temporary addresses.

The algorithm will then select the destination address, while giving a preference to reachable addresses with the smallest scope. The selection may be affected by system settings.

We note that [[RFC6724](#)] only applies for outgoing connections, such as those made by clients trying to use services offered by other hosts. When devices provide a service, the common pattern is to just wait for connections over all addresses configured on the device. For example, applications using the Sockets API will commonly `bind()` the listening socket to undefined address. This long-established behavior is appropriate for devices providing public services, but may have unexpected results for devices providing semi-private services, such as various forms of peer-to-peer or local-only applications.

This behavior leads to three problems: device tracking, discussed in [Section 4.1.1](#); unexpected address discovery, discussed in [Section 4.1.2](#); and availability outside the expected scope, discussed in [Section 4.1.3](#). These problems are caused in part by the limitations of available address selection API, presented in [Section 4.2](#).

[4.1. Issues Associated with Sub-optimal IPv6 Address Usage](#)

[4.1.1. Testing for the Presence of Node in the Network](#)

The stable addresses recommended in [[RFC8064](#)] use stable IID defined in [[RFC7217](#)]. One key part of that algorithm is that if a device connects to a given network at different times, it will always configure the same IPv6 addresses on that network. If the device hosts a service ready to accept connections on that stable address, adversaries can test the presence of the device on the network by attempting connections to that stable address. Stable addresses used by listening services will thus enable testing whether a specific device is returning to a particular network, which in a number of cases will be considered a privacy issue.

[4.1.2. Unexpected Address Discovery](#)

Systems like DNS-Based Service Discovery [[RFC6763](#)] allow clients to discover services within a limited scope, that can be defined by a domain name. These services are not advertised outside of that scope, and thus do not expect to be discovered by random parties on the Internet. Yet it appears that such services are easily discoverable if they listen for connections to IPv6 addresses that a client process also uses as source address when connecting to remote servers.

NOTE:

An example of such unexpected discovery is described in [[Hein](#)]. A network manager observed scanning traffic directed at the temporary addresses of local devices. Analysis shows that the scanners learned the addresses by observing the device contact an NTP service ([[RFC5905](#)]). The remote scanning was possible because the local devices were also accepting connections directed to the temporary addresses.

It is obvious from the example that the "attack surface" of the services is increased because they are bound to the same IPv6 addresses that are also used by clients for outgoing communications with remote systems. But the overlap between "client" and "server" addresses is only one part of the problem. Suppose that a device hosts both a video game and a home automation application. The video game users will be able to discover the IPv6 address of the game server. If the home automation server listens to the same IPv6 addresses, it is now exposed to connection attempts by all these users. That, too, increases the attack surface of the home automation server.

[4.1.3. Availability Outside the Expected Scope](#)

The IPv6 addressing architecture [[RFC4291](#)] defines multiple address scopes. In practice, devices are often configured with globally reachable unicast addresses, link local addresses, and Unique Local IPv6 Unicast Addresses (ULA) [[RFC4193](#)]. Availability outside the expected scope happens when a service is expected to be only available in some local scope, but inadvertently becomes available to remote parties. That could happen for example if a service is meant to be available only on a given link, but becomes reachable through ULA or through globally reachable addresses, or if a service is meant to be available only inside some organization's perimeter and becomes reachable through globally reachable addresses. It will happen in particular if a service intended for some local scope is programmed to bind to "unspecified" addresses, which in practice means every address configured for the device.

[4.2. Current Limitations in the Address Selection API](#)

Application developers using the Sockets API can "bind" a listening socket to a specific address, and ensure that the application is only reachable through that address. In theory, careful selection of the binding address could mitigate the three problems mentioned above. Binding services to temporary address could mitigate device tracking. Binding different services to different addresses could mitigate unexpected discovery. Binding services to link local addresses or ULA could mitigate availability outside the expected scope. However,

explicitly managing addresses adds significant complexity to the application development. It requires that application developers master addressing architectures subtleties, and implement logic that reacts adequately to connectivity events and address changes. Experience shows that application developers would probably prefer some much simpler solution.

In addition, we should note that many application developers use high level APIs that listen to TLS, HTTP, or some other application protocol. These high level APIs seldom provide detailed access to specific IP addresses, and typically default to listening to all available addresses.

5. IPv6 Address Considerations

5.1. Address Scope Considerations

The IPv6 address scope can, in some scenarios, limit the attack exposure of a node as a result of the implicit isolation provided by a non-global address scope. For example, a node that only employs link-local addresses may, in principle, only be exposed to attack from other nodes in the local link. Hosts employing only Unique Local Addresses (ULAs) may be more isolated from attack than those employing Global Unicast Addresses (GUAs), assuming that proper packet filtering is enforced at the network edge.

The potential protection provided by a non-global addresses should not be regarded as a complete security strategy, but rather as a form of "prophylactic" security (see [\[I-D.gont-opsawg-firewalls-analysis\]](#)).

We note that the use of non-global addresses is usually limited to a reduced type of applications/protocols that e.g. are only meant to operate on a reduced scope, and hence their applicability may be limited.

A discussion of ULA usage considerations can be found in [\[I-D.ietf-v6ops-ula-usage-considerations\]](#).

5.2. Address Stability Considerations

The stability of an address has two associated security/privacy implications:

- o Ability of an attacker to correlate network activity
- o Exposure to attack

For obvious reasons, an address that is employed for multiple communication instances allows the aforementioned network activities to be correlated. The longer an address is employed (i.e., the more stable it is), the longer such correlation will be possible. In the worst-case scenario, a stable address that is employed for multiple communication instances over time will allow all such activities to be correlated. On the other hand, if a host were to generate (and eventually "throw away") one new address for each communication instance (e.g., TCP connection), network activity correlation would be mitigated.

NOTE:

the use of constant IIDs (as in traditional SLAAC) result in addresses that, while not constant as a whole (since the prefix changes), contain a globally-unique value that leaks out the node "identity". Such addresses result in the worst possible security and privacy implications, and their use has been deprecated by [\[RFC8064\]](#).

Typically, when it comes to attack exposure, the longer an address is employed the longer an attacker is exposed to attacks (e.g. an attacker has more time to find the address in the first place [\[RFC7707\]](#)). While such exposure is traditionally associated with the stability of the address, the usage type of the address (see [Section 5.3](#)) may also have an impact on attack exposure.

A popular approach to mitigate network activity correlation is the use of "temporary addresses" [\[RFC4941\]](#). Temporary addresses are typically configured and employed along with stable addresses, with the temporary addresses employed for outgoing communications, and the stable addresses employed for incoming communications.

NOTE:

Ongoing work [\[I-D.gont-6man-non-stable-iids\]](#) aims at updating [\[RFC4941\]](#) such that temporary addresses can be employed without the need to configure stable addresses.

We note that the extent to which temporary addresses provide improved mitigation of network activity correlation and/or reduced attack exposure may be questionable and/or limited in some scenarios. For example, a temporary address that is reachable for, say, a few hours has a questionable "reduced exposure" (particularly when automated attack tools do not typically require such a long period of time to complete their task). Similarly, if network activity can be correlated for the life of such address (e.g., on the order of several hours), such period of time might be long enough for the attacker to correlate all the network activity he is meaning to correlate.

In order to better mitigate network activity correlation and/or possibly reduce host exposure, an implementation might want to either reduce the preferred lifetime of a temporary address, or even better, generate one new temporary address for each new transport protocol instance. However, the associated lifetime/stability of an address may have a negative impact on the network. For example, if a node were to employ "throw away" IPv6 addresses, or employ temporary addresses [[RFC4941](#)] with a short preferred lifetime, local nodes might need to maintain too many entries in their Neighbor Cache, and a number of devices (possibly enforcing security policies) might also need to keep such additional state.

Additionally, enforcing a maximum lifetime on IPv6 addresses may cause long-lived TCP connections to fail. For example, an address becoming "Invalid" (after transitioning through the "Preferred" and "Deprecated" states) would cause the TCP connections employing them to break. This, in turn, would cause e.g. long-lived SSH sessions to break/fail.

In some scenarios, attack exposure may be reduced by limiting the usage of temporary addresses to outbound connections, and prevent such addresses from being used for inbound connections (please see [Section 5.3](#)).

5.3. Usage Type Considerations

A node that employs one of its addresses to communicate with an external server (i.e., to perform an "outgoing connection") may cause such address to become exposed to attack. For example, once the external server receives an incoming connection, the corresponding server might launch an attack against the aforementioned address. A real-world instance of this type of scenario has been documented in [[Hein](#)].

However, we note that employing an IPv6 address for an outgoing communications need not increase the exposure of local services to other parties. For example, nodes could employ temporary addresses only for outgoing connections, but not for incoming connections. Thus, external nodes that learn about client's addresses could not really leverage such addresses for actively contacting the clients.

There are multiple ways in which this could possibly be achieved, with different implications. Namely:

- o Run a host-based or network-based firewall
- o Bind services to specific (explicit) addresses

- o Bind services only to stable addresses

A client could simply run a host-based firewall that only allows incoming connections on the stable addresses. This is clearly more of an operational way of achieving the desired functionality, and may require good firewall/host integration (e.g., the firewall should be able to tell stable vs. temporary addresses), may require the client to run additional firewall software for this specific purpose, etc. In other scenarios, a network-based firewall could be configured to allow outgoing communications from all internal addresses, but only allow incoming communications to stable addresses. For obvious reasons, this is generally only applicable to networks where incoming communications are allowed to a limited number of hosts/servers.

Services could be bound to specific (explicit) addresses, rather than to all locally-configured addresses. However, there are a number of short-comings associated with this approach. Firstly, an application would need to be able to learn all of its addresses and associated stability properties, something that tends to be non-trivial and non-portable, and that also makes applications protocol-dependent, unnecessarily. Secondly, the Sockets API does not really allow a socket to be bound to a subset of the node's addresses. That is, sockets can be bound to a single address or to all available addresses (wildcard), but not to a subset of all the configured addresses.

Binding services only to stable addresses provides a clean separation between addresses employed for client-like outgoing connections and server-like incoming connections. However, we currently lack an appropriate API for nodes to be able to specify that a socket should only be bound to stable addresses. Development of such an API should be considered for future work.

6. Possible Approaches for IPv6 Address Usage

There are a number of ways in which a system or network may affect which address (and how) may be employed for different services and cases. Namely,

- o TCP/IP stack address filtering
- o Application-based address filtering
- o Firewall-based address filtering

Clearly, the most elegant approach for address selection is for applications to be able to specify the properties of the addresses they are willing to employ by means of an API, such the TCP/IP stack

itself can "filter" which addresses are allowed to be employed for the given service/application. This relieves the application from dealing with low level details of networking, improves portability, and avoids duplicate code in applications. However, constraints in the current APIs (see [Section 4.2](#)) may limit the ability of application programmers from leveraging this technique.

Another possible approach is for applications to e.g. bind services to all available addresses, and perform the associated selection/filtering at the application level. While possible this has a number of drawbacks. Firstly, it would require applications to deal with low-level networking details, require that all the associated code be duplicated in all applications, and also negatively affect portability. Besides, performing address/selection filtering at the application level may not mitigate some possible threats. For example, port scanning will still be possible, since the aforementioned filtering will only be performed e.g. once UDP packets are received or TCP connections are established.

Finally, a firewall may be employed to filter addresses based on their intended usage. For example, a firewall may block incoming requests to all addresses except to some whitelisted addresses (such as the stable addresses of the node). This technique not only requires the use of a firewall (which may or may not be present), but also implies knowledge of the firewall regarding the desired properties of the addresses that each application/service is intended to use.

7. Advice on IPv6 Address Configuration

[TBD]

TODO: This section is expected to provide advice regarding the configuration of different addresses for different typical scenarios. e.g., when nodes may want to configure stable-only, temporary-only, or stable+temporary. In the most simple analysis, one might expect nodes in a typical enterprise network to employ only stable addresses. General-purpose nodes in a home or "trusted" network may want to employ both stable and temporary addresses. Finally, mobile nodes (e.g. when roaming across non-trusted networks) may want to employ only temporary addresses).

8. Advice on IPv6 Address Usage

[TBD]

TODO: This section is expected to provide recommendations regarding the usage of IPv6 addresses. Among others, it is expected to provide

recommendations regarding the usage of IPv6 addresses when providing network services. In the most simple form, one argues that nodes may want to employ only the smallest-scope applicable addresses (if available) and, if stable addresses are available, nodes may want to accept incoming connections on such addresses but *not* on temporary addresses.

9. Future Work

Some of the discussion in this document suggests that in order to fully benefit from the IPv6 addresses (in terms of e.g. increased availability of addresses and address types) additional work may be required in these areas:

- o Sockets API: The API may need to be extended such that a node may bind() only a subset of the available addresses, possibly by specifying a criteria (e.g. "only stable addresses", "only global", "only local", etc.).

The aforementioned work may be carried out in this document, or as a result of spin off documents.

10. IANA Considerations

There are no IANA registries within this document. The RFC-Editor can remove this section before publication of this document as an RFC.

11. Security Considerations

The security and privacy implications associated with the predictability and lifetime of IPv6 addresses has been analyzed in [[RFC7217](#)] [[RFC7721](#)], and [[RFC7707](#)]. This document complements and extends the aforementioned analysis by considering other IPv6 properties such as the address scope and address usage type.

This document also analyzes what properties are desirable for some popular scenarios, and provides advice regarding the configuration and usage of such addresses. Finally, it describes possible future standards-track work to allow for greater flexibility in IPv6 address usage.

12. Acknowledgements

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