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Significance of IPv6 Interface Identifiers
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Abstract

The IPv6 addressing architecture includes a unicast interface identifier that is used in the creation of many IPv6 addresses. Interface identifiers are formed by a variety of methods. This document clarifies that the bits in an interface identifier have no meaning and that the entire identifier should be treated as an opaque value. In particular, RFC 4291 defines a method by which the Universal and Group bits of an IEEE link-layer address are mapped into an IPv6 unicast interface identifier. This document clarifies that those two bits are significant only in the process of deriving interface identifiers from an IEEE link-layer address, and updates RFC 4291 accordingly.

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1. Introduction

IPv6 unicast addresses consist of a prefix followed by an Interface Identifier (IID). The IID is supposed to be unique on the links reached by routing to that prefix, giving an IPv6 address that is unique within the applicable scope (link local or global). According to the IPv6 addressing architecture [RFC4291], when a 64-bit IPv6 unicast IID is formed on the basis of an IEEE EUI-64 address, usually itself expanded from a 48-bit MAC address, a particular format must be used:

"For all unicast addresses, except those that start with the binary value 000, Interface IDs are required to be 64 bits long and to be constructed in Modified EUI-64 format."

Thus the specification assumes that the normal case is to transform an Ethernet-style address into an IID, but in practice, there are various methods of forming such an interface identifier.

The Modified EUI-64 format preserves the information provided by two particular bits in the MAC address:

- The "u/l" bit in a MAC address [IEEE802] is set to 0 to indicate universal scope (implying uniqueness) or to 1 to indicate local scope (without implying uniqueness). In an IID formed from a MAC address, this bit is simply known as the "u" bit and its value is inverted, i.e., 1 for universal scope and 0 for local scope. According to RFC 4291 and [RFC7042], the reason for this was to make it easier for network operators to manually configure local-scope IIDs.

  In an IID, this bit is in position 6, i.e., position 70 in the complete IPv6 address.

- The "i/g" bit in a MAC address is set to 1 to indicate group addressing (link-layer multicast). The value of this bit is preserved in an IID, where it is known as the "g" bit.

  In an IID, this bit is in position 7, i.e., position 71 in the complete IPv6 address.

This document discusses problems observed with the "u" and "g" bits as a result of the above requirements and the fact that various other methods of forming an IID have been defined, quite independently of the method described in Appendix A of RFC 4291. It then discusses the usefulness of these two bits and the significance of the bits in an IID in general. Finally, it updates RFC 4291 accordingly.

1.1. Terminology

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. Problem statement

In addition to IIDs formed from IEEE EUI-64 addresses, various new forms of IID have been defined, including temporary addresses

[RFC4941], Cryptographically Generated Addresses (CGAs) [RFC3972] [RFC4982], Hash-Based Addresses (HBAs) [RFC5535], and ISATAP addresses [RFC5214]. Other methods have been proposed, such as stable privacy addresses [I-D.ietf-6man-stable-privacy-addresses], and mapped addresses for 4rd [I-D.ietf-softwire-4rd]. In each case, the question of how to set the "u" and "g" bits has to be decided. For example, RFC 3972 specifies that they are both zero in CGAs, and RFC 4982 describes them as if they were reserved bits. The same applies to HBAs. On the other hand, RFC 4941 specifies that "u" must be zero but leaves "g" variable. The NAT64 addressing format [RFC6052] sets the whole byte containing "u" and "g" to zero.

Another case where the "u" and "g" bits are specified is in the Reserved IPv6 Subnet Anycast Address format [RFC2526], which states that "for interface identifiers in EUI-64 format, the universal/local bit in the interface identifier MUST be set to 0" (i.e., local) and requires that "g" bit to be set to 1. However, the text neither states nor implies any semantics for these bits in anycast addresses.

A common operational practice for well-known servers is to manually assign a small number as the IID, in which case "u" and "g" are both zero.

These cases illustrate that the statement quoted above from RFC 4291 requiring "Modified EUI-64 format" is inapplicable when applied to forms of IID that are not in fact based on an underlying EUI-64 address. In practice, the IETF has chosen to assign some 64-bit IIDs that have nothing to do with EUI-64.

A particular case is that of /127 prefixes for point-to-point links between routers, as standardised by [RFC6164]. The addresses on these links are undoubtedly global unicast addresses, but they do not have a 64-bit IID. The bits in the positions named "u" and "g" in such an IID have no special significance and their values are not specified.

Each time a new IID format is proposed, the question arises whether these bits have any meaning. Section 2.2.1 of RFC 7042 discusses the mechanics of the bit allocations but does not explain the purpose or usefulness of these bits in an IID. There is an IANA registry for reserved IID values [RFC5453] but again there is no explanation of the purpose of the "u" and "g" bits.

There was a presumption when IPv6 was designed and the IID format was first specified that a universally unique IID might prove to be very useful, for example to contribute to solving the multihoming problem. Indeed, the addressing architecture [RFC4291] states this explicitly:

"The use of the universal/local bit in the Modified EUI-64 format identifier is to allow development of future technology that can take advantage of interface identifiers with universal scope."

However, this has not so far proved to be the case. Also, there is evidence from the field that MAC addresses with universal scope are sometimes assigned to multiple MAC interfaces. There are recurrent reports of manufacturers assigning the same MAC address to multiple devices, and significant re-use of the same virtual MAC address is reported in virtual machine environments. Once transformed into IID format (with "u" = 1) these identifiers would purport to be universally unique but would in fact be ambiguous. This has no known

harmful effect as long as the replicated MAC addresses and IIDs are used on different layer 2 links. If they are used on the same link, of course there will be a problem, very likely interfering with link-layer transmission. If not, the problem will be detected by duplicate address detection [RFC4862] [RFC6775], but such an error can usually only be resolved by human intervention.

The conclusion from this is that the "u" bit is not a reliable indicator of universal uniqueness.

We note that Identifier-Locator Network Protocol (ILNP), a multihoming solution that might be expected to benefit from universally unique IIDs in modified EUI-64 format, does not in fact rely on them. ILNP uses its own format, defined as a Node Identifier [RFC6741]. ILNP has the constraint that a given Node Identifier must be unique within the context of a given Locator (i.e. within a single given IPv6 subnetwork). As we have just shown, the state of the "u" bit does not in any way guarantee such uniqueness, but duplicate address detection is available.

Thus, we can conclude that the value of the "u" bit in IIDs has no particular meaning. In the case of an IID created from a MAC address according to RFC 4291, its value is determined by the MAC address, but that is all.

An IPv6 IID should not be created from a MAC group address, so the "g" bit will normally be zero, but this value also has no particular meaning. Additionally, the "u" and the "g" bits are both meaningless in the format of an IPv6 multicast group ID [RFC3306] [RFC3307].

None of the above implies that there is a problem with using the "u" and "g" bits in MAC addresses as part of the process of generating IIDs from MAC addresses, or with specifying their values in other methods of generating IIDs. What it does imply is that, after an IID is generated by any method, no reliable deductions can be made from the state of the "u" and "g" bits; in other words, these bits have no useful semantics in an IID.

Once this is recognised, we can avoid the problematic confusion caused by these bits each time that a new form of IID is proposed.

3. Usefulness of the U and G Bits

Given that the "u" and "g" bits do not have a reliable meaning in an IID, it is relevant to consider what usefulness they do have.

If an IID is known or guessed to have been created according to RFC 4291, it could be transformed back into a MAC address. This can be

very helpful during operational fault diagnosis. For that reason, mapping the IEEE "u" and "g" bits into the IID has operational usefulness. However, it should be stressed that an IID with "u" = 1 and "g" = 0 might not be formed from a MAC address; on the contrary, it might equally result from another method. With other methods, there is no reverse transformation available.

Given that the values of the "u" and "g" bits in an IID have no particular meaning, new methods of IID formation are at liberty to use them as they wish, for example as additional pseudo-random bits to reduce the chances of duplicate IIDs.

4. The Role of Duplicate Address Detection

As mentioned above, Duplicate Address Detection (DAD) [RFC4862] is able to detect any case where a collision of two IIDs on the same link leads to a duplicated IPv6 address. The scope of DAD may be extended to a set of links by a DAD proxy [RFC6957] or by Neighbor Discovery Optimization [RFC6775]. Since DAD is mandatory for all nodes, there will be almost no case in which an IID collision, however unlikely it may be, is not detected. It is out of scope of most existing specifications to define the recovery action after a DAD failure, which is an implementation issue. If a manually created IID, or an IID derived from a MAC address according to RFC 4291, leads to a DAD failure, human intervention will most likely be required. However, as mentioned above, some methods of IID formation might produce IID values with "u" = 1 and "g" = 0 that are not based on a MAC address. With very low probability, such a value might collide with an IID based on a MAC address.

As stated in RFC 4862:

"On the other hand, if the duplicate link-local address is not formed from an interface identifier based on the hardware address, which is supposed to be uniquely assigned, IP operation on the interface MAY be continued."

Continued operation is only possible if a new IID is created. The best procedure to follow for this will depend on the IID formation method in use. For example, if an IID is formed by a pseudo-random process, that process could simply be repeated.

5. Clarification of Specifications

This section describes clarifications to the IPv6 specifications that result from the above discussion. Their aim is to reduce confusion while retaining the useful aspects of the "u" and "g" bits in IIDs.

The EUI-64 to IID transformation defined in the IPv6 addressing architecture [RFC4291] MUST be used for all cases where an IPv6 IID is derived from an IEEE MAC or EUI-64 address. With any other form of link layer address, an equivalent transformation SHOULD be used.

Specifications of other forms of 64-bit IID MUST specify how all 64 bits are set, but a generic semantic meaning for the "u" and "g" bits MUST NOT be defined. However, the method of generating IIDs for specific link types MAY define some local significance for certain bits.

In all cases, the bits in an IID have no generic semantics; in other words, they have opaque values. In fact, the whole IID value MUST be viewed as an opaque bit string by third parties, except possibly in the local context.

The following statement in section 2.5.1 of the IPv6 addressing architecture [RFC4291]:

"For all unicast addresses, except those that start with the binary value 000, Interface IDs are required to be 64 bits long and to be constructed in Modified EUI-64 format."

is replaced by:

"For all unicast addresses, except those that start with the binary value 000, Interface IDs are required to be 64 bits long. If derived from an IEEE MAC-layer address, they must be constructed in Modified EUI-64 format."

The following statement in section 2.5.1 of the IPv6 addressing architecture [RFC4291] is obsoleted:

"The use of the universal/local bit in the Modified EUI-64 format identifier is to allow development of future technology that can take advantage of interface identifiers with universal scope."

As far as is known, no existing implementation will be affected by these changes. The benefit is that future design discussions are simplified.

6. Security Considerations

No new security exposures or issues are raised by this document.

In some contexts, unpredictable IID values are considered beneficial to enhance privacy and defeat scanning attacks. The recognition that the IID value should be regarded as an opaque bit string is

consistent with methods of IID formation that result in unpredictable, pseudo-random values.

7. IANA Considerations

This document requests no immediate action by IANA. However, the following should be noted when considering any future proposed addition to the registry of reserved IID values, which requires Standards Action according to [RFC5453].

Full deployment of a new reserved IID value would require updates to IID generation code in every deployed IPv6 stack, so the technical justification for such a Standards Action would need to be extremely strong.

The preceding sentence and a reference to this document should be added to the Reserved IPv6 Interface Identifiers registry.

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