               Analysis of the 64-bit Boundary in IPv6 Addressing

Abstract

   The IPv6 unicast addressing format includes a separation between the
   prefix used to route packets to a subnet and the interface identifier
   used to specify a given interface connected to that subnet.
   Currently, the interface identifier is defined as 64 bits long for
   almost every case, leaving 64 bits for the subnet prefix. This
   document describes the advantages of this fixed boundary and analyzes
   the issues that would be involved in treating it as a variable
   boundary.

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1. Introduction

   Rather than simply overcoming the IPv4 address shortage by doubling
   the address size to 64 bits, IPv6 addresses were originally chosen to
   be 128 bits long to provide flexibility and new possibilities. In
   particular, the notion of a well-defined interface identifier was
   added to the IP addressing model. The IPv6 addressing architecture
   [RFC4291] specifies that a unicast address is divided into n bits of
   subnet prefix followed by (128-n) bits of interface identifier (IID).
   The bits in the IID may have significance only in the process of
   deriving the IID; once it is derived, the entire identifier should be
   treated as an opaque value [RFC7136]. Also, since IPv6 routing is
   entirely based on variable length prefixes (also known as variable
   length subnet masks), there is no basic architectural assumption that
   n has any particular fixed value. All IPv6 routing protocols support
   prefixes of any length up to /128.

   The IID is of basic importance in the IPv6 stateless address
   autoconfiguration (SLAAC) process [RFC4862]. However, it is
   important to understand that its length is a parameter in the SLAAC
   process, and it is determined in a separate link-type specific
   document (see the definition of "interface identifier" in Section 2
   of RFC 4862). The SLAAC protocol does not define its length or
   assume any particular length. Similarly, DHCPv6 [RFC3315] does not
   include a prefix length in its address assignment.

   The notion of a /64 boundary in the address was introduced after the
   initial design of IPv6, following a period when it was expected to be
   at /80. There were two motivations for setting it at /64. One was
   the original "8+8" proposal [ODELL] that eventually led to the
   Identifier-Locator Network Protocol (ILNP) [RFC6741], which required
   a fixed point for the split between local and wide-area parts of the
   address. The other was the expectation that 64-bit Extended Unique
   Identifier (EUI-64) Media Access Control (MAC) addresses would become
   widespread in place of 48-bit addresses, coupled with the plan at
   that time that auto-configured addresses would normally be based on
   interface identifiers derived from MAC addresses.

   As a result, RFC 4291 describes a method of forming interface
   identifiers from IEEE EUI-64 hardware addresses [IEEE802], and this
   specifies that such interface identifiers are 64 bits long. Various
   other methods of forming interface identifiers also specify a length
   of 64 bits. The addressing architecture, as modified by [RFC7136],
   states that:

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 de facto length of almost all IPv6 interface identifiers is
therefore 64 bits. The only documented exception is in [RFC6164],
which standardizes 127-bit prefixes for point-to-point links between
routers, among other things, to avoid a loop condition known as the
ping-pong problem.

With that exception, and despite the comments above about the routing
architecture and the design of SLAAC, using an IID shorter than 64
bits and a subnet prefix longer than 64 bits is outside the current
IPv6 specifications, so results may vary.

The question is often asked why the subnet prefix boundary is set
rigidly at /64. The first purpose of this document is to explain the
advantages of the fixed IID length. Its second purpose is to
analyze, in some detail, the effects of hypothetically varying the
IID length. The fixed-length limits the practical length of a
routing prefix to 64 bits, whereas architecturally, and from the
point of view of routing protocols, it could be any value up to /128,
as in the case of host routes. Whatever the length of the IID, the
longest match is done on the concatenation of prefix and IID. Here,
we mainly discuss the question of a shorter IID, which would allow a
longer subnet prefix. The document makes no proposal for a change to
the IID length.

The following three sections describe, in turn, the advantages of the
fixed-length IID, some arguments for shorter lengths, and the
expected effects of varying the length.

2. Advantages of a Fixed Identifier Length

As mentioned in Section 1, the existence of an IID of a given length
is a necessary part of IPv6 stateless address autoconfiguration
(SLAAC) [RFC4862]. This length is normally the same for all nodes on
a given link that is running SLAAC. Even though this length is a
parameter for SLAAC, determined separately for the link-layer media
type of each interface, a globally fixed IID length for all link-
layer media is the simplest solution and is consistent with the
principles of Internet host configuration described in [RFC5505].

An interface identifier of significant length, clearly separated from
the subnet prefix, makes it possible to limit the traceability of a
host computer by varying the identifier. This is discussed further
in Section 4.5.

An interface identifier of significant length guarantees that there
are always enough addresses in any subnet to add one or more real or
virtual interfaces. There might be other limits, but IP addressing
will never get in the way.

The addressing architecture [RFC4291] [RFC7136] sets the IID length
at 64 bits for all unicast addresses and therefore for all media
supporting SLAAC. An immediate effect of fixing the IID length at 64
bits is, of course, that it fixes the subnet prefix length also at 64
bits, regardless of the aggregate prefix assigned to the site
concerned, which in accordance with [RFC6177] should be /56 or
shorter. This situation has various specific advantages:

o Everything is the same. Compared to IPv4, there is no more
   calculating leaf subnet sizes, no more juggling between subnets,
   and fewer consequent errors. Network design is therefore simpler
   and much more straightforward. This is of importance for all
   types of networks -- enterprise, campus, small office, or home
   networks -- and for all types of operator, from professional to
   consumer.

o Adding a subnet is easy -- just take another /64 from the pool.
   No estimates, calculations, consideration, or judgement is needed.

o Router configurations are homogeneous and easier to understand.

o Documentation is easier to write and easier to read; training is
   easier.

The remainder of this document describes arguments that have been
made against the current fixed IID length and analyzes the effects of
a possible change. However, the consensus of the IETF is that the
benefits of keeping the length fixed at 64 bits and the practical
difficulties of changing it outweigh the arguments for change.

3. Arguments for Shorter Identifier Lengths

   In this section, we describe arguments for scenarios where shorter
   IIDs, implying prefixes longer than /64, have been used or proposed.

3.1. Insufficient Address Space Delegated

   A site may not be delegated a sufficiently generous prefix from which
   to allocate a /64 prefix to all of its internal subnets. In this
   case, the site may either determine that it does not have enough
   address space to number all its network elements and thus, at the
   very best, be only partially operational, or it may choose to use

internal prefixes longer than /64 to allow multiple subnets and the
hosts within them to be configured with addresses.

In this case, the site might choose, for example, to use a /80 per
subnet in combination with hosts using either manually configured
addressing or DHCPv6 [RFC3315].

Scenarios that have been suggested where an insufficient prefix might
be delegated include home or small office networks, vehicles,
building services, and transportation services (e.g., road signs).
It should be noted that the homenet architecture text [RFC7368]
states that Customer Premises Equipment (CPE) should consider the
lack of sufficient address space to be an error condition, rather
than using prefixes longer than /64 internally.

Another scenario occasionally suggested is one where the Internet
address registries actually begin to run out of IPv6 prefix space,
such that operators can no longer assign reasonable prefixes to users
in accordance with [RFC6177]. It is sometimes suggested that
assigning a prefix such as /48 or /56 to every user site (including
the smallest) as recommended by [RFC6177] is wasteful. In fact, the
currently released unicast address space, 2000::/3, contains 35
trillion /48 prefixes ((2**45 = 35,184,372,088,832), of which only a
small fraction have been allocated. Allowing for a conservative
estimate of allocation efficiency, i.e., an HD-ratio of 0.94
[RFC4692], approximately 5 trillion /48 prefixes can be allocated.
Even with a relaxed HD-ratio of 0.89, approximately one trillion /48
prefixes can be allocated. Furthermore, with only 2000::/3 currently
committed for unicast addressing, we still have approximately 85% of
the address space in reserve. Thus, there is no objective risk of
prefix depletion by assigning /48 or /56 prefixes even to the
smallest sites.

3.2. Hierarchical Addressing

Some operators have argued that more prefix bits are needed to allow
an aggregated hierarchical addressing scheme within a campus or
corporate network. However, if a campus or enterprise gets a /48
prefix (or shorter), then that already provides 16 bits for
hierarchical allocation. In any case, flat IGP routing is widely and
successfully used within rather large networks, with hundreds of
routers and thousands of end systems. Therefore, there is no
objective need for additional prefix bits to support hierarchy and
aggregation within enterprises.

3.3. Audit Requirement

   Some network operators wish to know and audit nodes that are active
   on a network, especially those that are allowed to communicate off-
   link or off-site. They may also wish to limit the total number of
   active addresses and sessions that can be sourced from a particular
   host, LAN, or site, in order to prevent potential resource-depletion
   attacks or other problems spreading beyond a certain scope of
   control. It has been argued that this type of control would be
   easier if only long network prefixes with relatively small numbers of
   possible hosts per network were used, reducing the discovery problem.
   However, such sites most typically operate using DHCPv6, which means
   that all legitimate hosts are automatically known to the DHCPv6
   servers, which is sufficient for audit purposes. Such hosts could,
   if desired, be limited to a small range of IID values without
   changing the /64 subnet length. Any hosts inadvertently obtaining
   addresses via SLAAC can be audited through Neighbor Discovery (ND)
   logs.

3.4. Concerns over ND Cache Exhaustion

   A site may be concerned that it is open to ND cache exhaustion
   attacks [RFC3756], whereby an attacker sends a large number of
   messages in rapid succession to a series of (most likely inactive)
   host addresses within a specific subnet. Such an attack attempts to
   fill a router's ND cache with ND requests pending completion, which
   results in denying correct operation to active devices on the
   network.

   One potential way to mitigate this attack would be to consider using
   a /120 prefix, thus limiting the number of addresses in the subnet to
   be similar to an IPv4 /24 prefix, which should not cause any concerns
   for ND cache exhaustion. Note that the prefix does need to be quite
   long for this scenario to be valid. The number of theoretically
   possible ND cache slots on the segment needs to be of the same order
   of magnitude as the actual number of hosts. Thus, small increases
   from the /64 prefix length do not have a noticeable impact; even 2^{32}
   potential entries, a factor of two billion decrease compared to 2^{64},
   is still more than enough to exhaust the memory on current routers.
   Given that most link-layer mappings cause SLAAC to assume a 64-bit
   network boundary, in such an approach hosts would likely need to use
   DHCPv6 or be manually configured with addresses.

   It should be noted that several other mitigations of the ND cache
   attack are described in [RFC6583], and that limiting the size of the
   cache and the number of incomplete entries allowed would also defeat
   the attack. For the specific case of a point-to-point link between
   routers, this attack is indeed mitigated by a /127 prefix [RFC6164].

4. Effects of Varying the Interface Identifier Length

   This section of the document analyzes the impact and effects of
   varying the length of an IPv6 unicast IID by reducing it to less than
   64 bits.

4.1. Interaction with IPv6 Specifications

   The precise 64-bit length of the IID is widely mentioned in numerous
   RFCs describing various aspects of IPv6. It is not straightforward
   to distinguish cases where this has normative impact or affects
   interoperability. This section aims to identify specifications that
   contain an explicit reference to the 64-bit length. Regardless of
   implementation issues, the RFCs themselves would all need to be
   updated if the 64-bit rule was changed, even if the updates were
   small, which would involve considerable time and effort.

   First and foremost, the RFCs describing the architectural aspects of
   IPv6 addressing explicitly state, refer, and repeat this apparently
   immutable value: Addressing Architecture [RFC4291], IPv6 Address
   Assignment to End Sites [RFC6177], Reserved IIDs [RFC5453], and ILNP
   Node Identifiers [RFC6741]. Customer edge routers impose /64 for
   their interfaces [RFC7084]. The IPv6 Subnet Model [RFC5942] points
   out that the assumption of a /64 prefix length is a potential
   implementation error.

   Numerous IPv6-over-foo documents make mandatory statements with
   respect to the 64-bit length of the IID to be used during the
   Stateless Autoconfiguration. These documents include [RFC2464]
   (Ethernet), [RFC2467] (Fiber Distributed Data Interface (FDDI)),
   [RFC2470] (Token Ring), [RFC2492] (ATM), [RFC2497] (ARCnet),
   [RFC2590] (Frame Relay), [RFC3146] (IEEE 1394), [RFC4338] (Fibre
   Channel), [RFC4944] (IEEE 802.15.4), [RFC5072] (PPP), [RFC5121]
   [RFC5692] (IEEE 802.16), [RFC2529] (6over4), [RFC5214] (Intra-Site
   Automatic Tunnel Addressing Protocol (ISATAP)), [AERO-TRANS]
   (Asymmetric Extended Route Optimization (AERO)), [BLUETOOTH-LE]
   (BLUETOOTH Low Energy), [IPv6-TRANS] (IPv6 over MS/TP), and
   [IPv6-G9959] (IPv6 packets over ITU-T G.9959).

   To a lesser extent, the address configuration RFCs themselves may in
   some ways assume the 64-bit length of an IID (e.g, RFC 4862 for the
   link-local addresses, DHCPv6 for the potentially assigned EUI-
   64-based IP addresses, and Optimistic Duplicate Address Detection
   [RFC4429] that computes 64-bit-based collision probabilities).

   The Multicast Listener Discovery Version 1 (MLDv1) [RFC2710] and
   MLDv2 [RFC3810] protocols mandate that all queries be sent with a
   link-local source address, with the exception of MLD messages sent

using the unspecified address when the link-local address is
tentative [RFC3590]. At the time of publication of RFC 2710, the
IPv6 addressing architecture specified link-local addresses with
64-bit interface identifiers. MLDv2 explicitly specifies the use of
the fe80::/64 link-local prefix and bases the querier election
algorithm on the link-local subnet prefix of length /64.

The "IPv6 Flow Label Specification" [RFC6437] gives an example of a
20-bit hash function generation, which relies on splitting an IPv6
address in two equally sized, 64-bit-length parts.

The basic transition mechanisms [RFC4213] refer to IIDs of length 64
for link-local addresses; other transition mechanisms such as Teredo
[RFC4380] assume the use of IIDs of length 64. Similar assumptions
are found in 6to4 [RFC3056] and 6rd [RFC5969]. Translation-based
transition mechanisms such as NAT64 and NPTv6 have some dependency on
prefix length, discussed below.

The proposed method [RFC7278] of extending an assigned /64 prefix
from a smartphone's cellular interface to its WiFi link relies on
prefix length, and implicitly on the length of the IID, to be valued
at 64.

The Cryptographically Generated Addresses (CGA) and Hash-Based
Addresses (HBA) specifications rely on the 64-bit identifier length
(see below), as do the Privacy extensions [RFC4941] and some examples
in "Internet Key Exchange Version 2 (IKEv2)" [RFC7296].

464XLAT [RFC6877] explicitly mentions acquiring /64 prefixes.
However, it also discusses the possibility of using the interface
address on the device as the end point for the traffic, thus
potentially removing this dependency.

[RFC2526] reserves a number of subnet anycast addresses by reserving
some anycast IIDs. An anycast IID so reserved cannot be less than 7
bits long. This means that a subnet prefix length longer than /121
is not possible, and a subnet of exactly /121 would be useless since
all its identifiers are reserved. It also means that half of a /120
is reserved for anycast. This could of course be fixed in the way
described for /127 in [RFC6164], i.e., avoiding the use of anycast
within a /120 subnet. Note that support for "on-link anycast" is a
standard IPv6 neighbor discovery capability [RFC4861] [RFC7094];
therefore, applications and their developers would expect it to be
available.

The Mobile IP home network models [RFC4887] rely heavily on the /64
subnet length and assume a 64-bit IID.

While preparing this document, it was noted that many other IPv6
specifications refer to mandatory alignment on 64-bit boundaries,
64-bit data structures, 64-bit counters in MIBs, 64-bit sequence
numbers and cookies in security, etc. Finally, the number "64" may
be considered "magic" in some RFCs, e.g., 64k limits in DNS and
Base64 encodings in MIME. None of this has any influence on the
length of the IID but might confuse a careless reader.

4.2. Possible Failure Modes

This section discusses several specific aspects of IPv6 where we can
expect operational failures with subnet prefixes other than /64.

o Router implementations: Router implementors might interpret IETF
   specifications such as [RFC6164] and [RFC7136] as indicating that
   prefixes between /65 and /126 (inclusive) for unicast packets on-
   the-wire are invalid and that operational practices that utilize
   prefix lengths in this range may fail on some devices, as
   discussed in Section 4.3.2.

o Multicast: [RFC3306] defines a method for generating IPv6
   multicast group addresses based on unicast prefixes. This method
   assumes a longest prefix of 64 bits. If a longer prefix is used,
   there is no way to generate a specific multicast group address
   using this method. In such cases, the administrator would need to
   use an "artificial" prefix from within their allocation (a /64 or
   shorter) from which to generate the group address. This prefix
   would not correspond to a real subnet.

   Similarly, [RFC3956], which specifies the Embedded Rendezvous
   Point (RP)) allowing IPv6 multicast rendezvous point addresses to
   be embedded in the multicast group address, would also fail, as
   the scheme assumes a maximum prefix length of 64 bits.

o CGA: The Cryptographically Generated Address format [RFC3972] is
   heavily based on a /64 interface identifier. [RFC3972] has
   defined a detailed algorithm showing how to generate a 64-bit
   interface identifier from a public key and a 64-bit subnet prefix.
   Changing the /64 boundary would certainly invalidate the current
   CGA definition. However, the CGA might benefit in a redefined
   version if more bits are used for interface identifiers (which
   means shorter prefix length). For now, 59 bits are used for
   cryptographic purposes. The more bits are available, the stronger
   CGA could be. Conversely, longer prefixes would weaken CGA.

o NAT64: Both stateless NAT64 [RFC6052] and stateful NAT64 [RFC6146]
   are flexible for the prefix length. [RFC6052] has defined
   multiple address formats for NAT64. In Section 2 of

"IPv4-Embedded IPv6 Address Prefix and Format" [RFC6052], the
network-specific prefix could be one of /32, /40, /48, /56, /64,
and /96. The remaining part of the IPv6 address is constructed by
a 32-bit IPv4 address, an 8-bit u byte and a variable length
suffix (there is no u byte and suffix in the case of the 96-bit
Well-Known Prefix). NAT64 is therefore OK with a subnet boundary
out to /96 but not longer.

o NPTv6: IPv6-to-IPv6 Network Prefix Translation [RFC6296] is also
   bound to /64 boundary. NPTv6 maps a /64 prefix to another /64
   prefix. When the NPTv6 Translator is configured with a /48 or
   shorter prefix, the 64-bit interface identifier is kept unmodified
   during translation. However, the /64 boundary might be changed as
   long as the "inside" and "outside" prefixes have the same length.

o ILNP: Identifier-Locator Network Protocol (ILNP) [RFC6741] is
   designed around the /64 boundary, since it relies on locally
   unique 64-bit node identifiers (in the interface identifier
   field). While a redesign to use longer prefixes is not
   inconceivable, this would need major changes to the existing
   specification for the IPv6 version of ILNP.

o Shim6: The Multihoming Shim Protocol for IPv6 (Shim6) [RFC5533] in
   its insecure form treats IPv6 addresses as opaque 128-bit objects.
   However, to secure the protocol against spoofing, it is essential
   to either use CGAs (see above) or HBAs [RFC5535]. Like CGAs, HBAs
   are generated using a procedure that assumes a 64-bit identifier.
   Therefore, in effect, secure shim6 is affected by the /64 boundary
   exactly like CGAs.

o Duplicate address risk: If SLAAC was modified to work with shorter
   IIDs, the statistical risk of hosts choosing the same pseudo-
   random identifier [RFC7217] would increase correspondingly. The
   practical impact of this would range from slight to dramatic,
   depending on how much the IID length was reduced. In particular,
   a /120 prefix would imply an 8-bit IID and address collisions
   would be highly probable.

o The link-local prefix: While RFC 4862 is careful not to define any
   specific length of link-local prefix within fe80::/10, the
   addressing architecture [RFC4291] does define the link-local IID
   length to be 64 bits. If different hosts on a link used IIDs of
   different lengths to form a link-local address, there is potential
   for confusion and unpredictable results. Typically today the
   choice of 64 bits for the link-local IID length is hard-coded per
   interface, in accordance with the relevant IPv6-over-foo
   specification, and systems behave as if the link-local prefix was
   actually fe80::/64. There might be no way to change this except

conceivably by manual configuration, which will be impossible if
the host concerned has no local user interface.

It goes without saying that if prefixes longer than /64 are to be
used, all hosts must be capable of generating IIDs shorter than 64
bits, in order to follow the auto-configuration procedure correctly
[RFC4862].

4.3. Experimental Observations

4.3.1. Survey of the processing of Neighbor Discovery Options with
        Prefixes Other than /64

This section provides a survey of the processing of Neighbor
Discovery options that include prefixes that are different than /64.

The behavior of nodes was assessed with respect to the following
options:

o PIO-A: Prefix Information Option (PIO) [RFC4861] with the A bit
   set.

o PIO-L: Prefix Information Option (PIO) [RFC4861] with the L bit
   set.

o PIO-AL: Prefix Information Option (PIO) [RFC4861] with both the A
   and L bits set.

o RIO: Route Information Option (RIO) [RFC4191].

In the tables below, the following notation is used:

NOT-SUP:
   This option is not supported (i.e., it is ignored no matter the
   prefix length used).

LOCAL:
   The corresponding prefix is considered "on-link".

ROUTE:
   The corresponding route is added to the IPv6 routing table.

NOT-DEF:
   The default configuration is NOT-SUP, but there is an option to
   enable ROUTE.

IGNORE:
   The option is ignored as an error.

```
+--------------------+--------+-------+--------+---------+
|  Operating System  | PIO-A  | PIO-L | PIO-AL |   RIO   |
+--------------------+--------+-------+--------+---------+
|     FreeBSD 9.0     | IGNORE | LOCAL | LOCAL  | NOT-SUP |
+--------------------+--------+-------+--------+---------+
|   Linux 3.0.0-15   | IGNORE | LOCAL | LOCAL  | NOT-DEF |
+--------------------+--------+-------+--------+---------+
|   Linux-current    | IGNORE | LOCAL | LOCAL  | NOT-DEF |
+--------------------+--------+-------+--------+---------+
|     NetBSD 5.1     | IGNORE | LOCAL | LOCAL  | NOT-SUP |
+--------------------+--------+-------+--------+---------+
|  OpenBSD-current   | IGNORE | LOCAL | LOCAL  | NOT-SUP |
+--------------------+--------+-------+--------+---------+
|     Win XP SP2     | IGNORE | LOCAL | LOCAL  |  ROUTE  |
+--------------------+--------+-------+--------+---------+
| Win 7 Home Premium | IGNORE | LOCAL | LOCAL  |  ROUTE  |
+--------------------+--------+-------+--------+---------+
```

       Table 1: Processing of ND options with prefixes longer than /64

```
+--------------------+--------+-------+--------+---------+
|  Operating System  | PIO-A  | PIO-L | PIO-AL |   RIO   |
+--------------------+--------+-------+--------+---------+
|     FreeBSD 9.0     | IGNORE | LOCAL | LOCAL  | NOT-SUP |
+--------------------+--------+-------+--------+---------+
|   Linux 3.0.0-15   | IGNORE | LOCAL | LOCAL  | NOT-DEF |
+--------------------+--------+-------+--------+---------+
|   Linux-current    | IGNORE | LOCAL | LOCAL  | NOT-DEF |
+--------------------+--------+-------+--------+---------+
|     NetBSD 5.1     | IGNORE | LOCAL | LOCAL  | NOT-SUP |
+--------------------+--------+-------+--------+---------+
|  OpenBSD-current   | IGNORE | LOCAL | LOCAL  | NOT-SUP |
+--------------------+--------+-------+--------+---------+
|     Win XP SP2     | IGNORE | LOCAL | LOCAL  |  ROUTE  |
+--------------------+--------+-------+--------+---------+
| Win 7 Home Premium | IGNORE | LOCAL | LOCAL  |  ROUTE  |
+--------------------+--------+-------+--------+---------+
```

      Table 2: Processing of ND options with prefixes shorter than /64

   The results obtained can be summarized as follows:

   o The "A" bit in the Prefix Information Options is honored only if
      the prefix length is 64. This is consistent with [RFC4862], at
      least for the case where the IID length is defined to be 64 bits
      in the corresponding link-type-specific document, which is the

case for all currently published such documents. [RFC4862]
defines the case where the sum of the advertised prefix length and
the IID length does not equal 128 as an error condition.

o The "L" bit in the Prefix Information Options is honored for any
   arbitrary prefix length (whether shorter or longer than /64).

o Nodes that support the Route Information Option allow such routes
   to be specified with prefixes of any arbitrary length (whether
   shorter or longer than /64)

4.3.2. Other Observations

Participants in the V6OPS working group have indicated that some
forwarding devices have been shown to work correctly with long
prefixes such as /80 or /96. Indeed, it is to be expected that
forwarding based on the longest prefix match will work for any prefix
length, and no reports of this completely failing have been noted.
Also, DHCPv6 is in widespread use without any dependency on the /64
boundary. Reportedly, there are deployments of /120 subnets
configured using DHCPv6.

There have been definite reports that some routers have a performance
drop-off or even resource exhaustion for prefixes longer than /64 due
to design issues. In particular, some routing chip designs allocate
much less space for longer prefixes than for prefixes up to /64 for
the sake of savings in memory, power, and lookup latency. Some
devices need special-case code to handle point-to-point links
according to [RFC6164].

It has been reported that at least one type of switch has a content-
addressable memory limited to 144 bits, which is indeed a typical
value for commodity components [TCAM]. This means that packet
filters or access control lists cannot be defined based on 128-bit
addresses and two 16-bit port numbers; the longest prefix that could
be used in such a filter is a /112.

4.4. Implementation and Deployment Issues

From an early stage, implementations and deployments of IPv6 assumed
the /64 subnet length, even though routing was based on prefixes of
any length. As shown above, this became anchored in many
specifications (Section 4.1) and in important aspects of
implementations commonly used in local area networks (Section 4.3).
In fact, a programmer might be lulled into assuming a comfortable
rule of thumb that subnet prefixes are always /64 and an IID is
always of length 64. Apart from the limited evidence in
Section 4.3.1, we cannot tell without code inspections or tests

whether existing stacks are able to handle a flexible IID length or
whether they would require modification to do so. A conforming
implementation of an IPv6-over-foo that specifies a 64 bit IID for
foo links will of course only support 64. But in a well designed
stack, the IP layer itself will treat that 64 as a parameter, so
changing the IID length in the IPv6-over-foo code should be all that
is necessary.

The main practical consequence of the existing specifications is that
deployments in which longer subnet prefixes are used cannot make use
of SLAAC-configured addresses and require either manually configured
addresses or DHCPv6. To reverse this argument, if it was considered
desirable to allow auto-configured addresses with subnet prefixes
longer than /64, all of the specifications identified above as
depending on /64 would have to be modified with due regard to
interoperability with unmodified stacks. In fact, [RFC7217] allows
for this possibility. Then, modified stacks would have to be
developed and deployed. It might be the case that some stacks
contain dependencies on the /64 boundary that are not directly
implied by the specifications, and any such hidden dependencies would
also need to be found and removed.

At least one DHCPv6 client unconditionally installs a /64 prefix as
on-link when it configures an interface with an address, although
some specific operating system vendors seem to change this default
behavior by tweaking a client-side script. This is in clear
violation of the IPv6 subnet model [RFC5942]. The motivation for
this choice is that if there is no router on the link, the hosts
would fail to communicate with each other using the configured
addresses because the "on-link assumption" was removed in [RFC4861].
This is not really about the magic number of 64, but an
implementation may sometimes pick an arbitrary value of prefix length
due to the removal of the on-link assumption, and the value chosen
will most likely be 64.

Typical IP Address Management (IPAM) tools treat /64 as the default
subnet length but allow users to specify longer subnet prefixes if
desired. Clearly, all IPAM tools and network management systems
would need to be checked in detail.

Finally, IPv6 is already deployed at many sites, with a large number
of staff trained on the basis of the existing standards, supported by
documentation and tools based on those standards. Numerous existing
middlebox devices are also based on those standards. These people,
documents, tools, and devices represent a very large investment that
would be seriously impacted by a change in the /64 boundary.

4.5. Privacy Issues

   The length of the interface identifier has implications for privacy
   [ADDRESS-PRIVACY]. In any case in which the value of the identifier
   is intended to be hard to guess, whether or not it is
   cryptographically generated, it is apparent that more bits are
   better. For example, if there are only 20 bits to be guessed, then
   at most just over a million guesses are needed, which is well within
   the capacity of a low-cost attack mechanism. It is hard to state in
   general how many bits are enough to protect privacy, since this
   depends on the resources available to the attacker, but it seems
   clear that a privacy solution needs to resist an attack requiring
   billions rather than millions of guesses. Trillions would be better,
   suggesting that at least 40 bits should be available. Thus, we can
   argue that subnet prefixes longer than say /80 might raise privacy
   concerns by making the IID guessable.

   A prefix long enough to limit the number of addresses comparably to
   an IPv4 subnet, such as /120, would create exactly the same situation
   for privacy as IPv4 except for the absence of NAT. In particular, a
   host would be forced to pick a new IID when roaming to a new network
   to avoid collisions. As mentioned earlier, it is likely that SLAAC
   will not be used on such a subnet.

5. Security Considerations

   In addition to the privacy issues mentioned in Section 4.5 and the
   issues mentioned with CGAs and HBAs in Section 4.2, the length of the
   subnet prefix affects the matter of defense against scanning attacks
   [HOST-SCANNING]. Assuming the attacker has discovered or guessed the
   prefix length, a longer prefix reduces the space that the attacker
   needs to scan, e.g., to only 256 addresses if the prefix is /120. On
   the other hand, if the attacker has not discovered the prefix length
   and assumes it to be /64, routers can trivially discard attack
   packets that do not fall within an actual subnet.

   However, assume that an attacker finds one valid address "A" and
   assumes that it is within a long prefix such as a /120. The attacker
   then starts a scanning attack by scanning "outwards" from A, by
   trying A+1, A-1, A+2, A-2, etc. This attacker will easily find all
   hosts in any subnet with a long prefix, because they will have
   addresses close to A. We therefore conclude that any prefix
   containing densely packed valid addresses is vulnerable to a scanning
   attack, without the attacker needing to guess the prefix length.
   Therefore, to preserve IPv6's advantage over IPv4 in resisting
   scanning attacks, it is important that subnet prefixes are short
   enough to allow sparse allocation of identifiers within each subnet.
   The considerations are similar to those for privacy, and we can again

argue that prefixes longer than say /80 might significantly increase
vulnerability. Ironically, this argument is exactly converse to the
argument for longer prefixes to resist an ND cache attack, as
described in Section 3.4.

Denial-of-service attacks related to Neighbor Discovery are discussed
in Section 3.4 and in [RFC6583]. One of the mitigations suggested by
that document is "sizing subnets to reflect the number of addresses
actually in use", but the fact that this greatly simplifies scanning
attacks is not noted. For further discussion of scanning attacks,
see [HOST-SCANNING].

Note that, although not known at the time of writing, there might be
other resource exhaustion attacks available, similar in nature to the
ND cache attack. We cannot exclude that such attacks might be
exacerbated by sparsely populated subnets such as a /64. It should
also be noted that this analysis assumes a conventional deployment
model with a significant number of end-systems located in a single
LAN broadcast domain. Other deployment models might lead to
different conclusions.

6. References

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