                    IPv6 Stateless Address Autoconfiguration

Status of this Memo

Copyright Notice

Abstract

   This document specifies the steps a host takes in deciding how to
   autoconfigure its interfaces in IP version 6. The autoconfiguration
   process includes creating a link-local address and verifying its
   uniqueness on a link, determining what information should be
   autoconfigured (addresses, other information, or both), and in the
   case of addresses, whether they should be obtained through the
   stateless mechanism, the stateful mechanism, or both. This document
   defines the process for generating a link-local address, the process
   for generating site-local and global addresses via stateless address
   autoconfiguration, and the Duplicate Address Detection procedure. The
   details of autoconfiguration using the stateful protocol are
   specified elsewhere.

Table of Contents

1. INTRODUCTION

   This document specifies the steps a host takes in deciding how to
   autoconfigure its interfaces in IP version 6. The autoconfiguration
   process includes creating a link-local address and verifying its
   uniqueness on a link, determining what information should be
   autoconfigured (addresses, other information, or both), and in the
   case of addresses, whether they should be obtained through the
   stateless mechanism, the stateful mechanism, or both. This document
   defines the process for generating a link-local address, the process
   for generating site-local and global addresses via stateless address
   autoconfiguration, and the Duplicate Address Detection procedure. The
   details of autoconfiguration using the stateful protocol are
   specified elsewhere.

   IPv6 defines both a stateful and stateless address autoconfiguration
   mechanism. Stateless autoconfiguration requires no manual
   configuration of hosts, minimal (if any) configuration of routers,
   and no additional servers. The stateless mechanism allows a host to
   generate its own addresses using a combination of locally available
   information and information advertised by routers. Routers advertise
   prefixes that identify the subnet(s) associated with a link, while
   hosts generate an "interface identifier" that uniquely identifies an
   interface on a subnet. An address is formed by combining the two. In
   the absence of routers, a host can only generate link-local
   addresses. However, link-local addresses are sufficient for allowing
   communication among nodes attached to the same link.

In the stateful autoconfiguration model, hosts obtain interface
addresses and/or configuration information and parameters from a
server. Servers maintain a database that keeps track of which
addresses have been assigned to which hosts. The stateful
autoconfiguration protocol allows hosts to obtain addresses, other
configuration information or both from a server. Stateless and
stateful autoconfiguration complement each other. For example, a host
can use stateless autoconfiguration to configure its own addresses,
but use stateful autoconfiguration to obtain other information.
Stateful autoconfiguration for IPv6 is the subject of future work
[DHCPv6].

The stateless approach is used when a site is not particularly
concerned with the exact addresses hosts use, so long as they are
unique and properly routable. The stateful approach is used when a
site requires tighter control over exact address assignments. Both
stateful and stateless address autoconfiguration may be used
simultaneously. The site administrator specifies which type of
autoconfiguration to use through the setting of appropriate fields in
Router Advertisement messages [DISCOVERY].

IPv6 addresses are leased to an interface for a fixed (possibly
infinite) length of time. Each address has an associated lifetime
that indicates how long the address is bound to an interface. When a
lifetime expires, the binding (and address) become invalid and the
address may be reassigned to another interface elsewhere in the
Internet. To handle the expiration of address bindings gracefully, an
address goes through two distinct phases while assigned to an
interface. Initially, an address is "preferred", meaning that its use
in arbitrary communication is unrestricted. Later, an address becomes
"deprecated" in anticipation that its current interface binding will
become invalid. While in a deprecated state, the use of an address is
discouraged, but not strictly forbidden. New communication (e.g.,
the opening of a new TCP connection) should use a preferred address
when possible. A deprecated address should be used only by
applications that have been using it and would have difficulty
switching to another address without a service disruption.

To insure that all configured addresses are likely to be unique on a
given link, nodes run a "duplicate address detection" algorithm on
addresses before assigning them to an interface. The Duplicate
Address Detection algorithm is performed on all addresses,
independent of whether they are obtained via stateless or stateful
autoconfiguration. This document defines the Duplicate Address
Detection algorithm.

The autoconfiguration process specified in this document applies only
to hosts and not routers. Since host autoconfiguration uses
information advertised by routers, routers will need to be configured
by some other means. However, it is expected that routers will
generate link-local addresses using the mechanism described in this
document. In addition, routers are expected to successfully pass the
Duplicate Address Detection procedure described in this document on
all addresses prior to assigning them to an interface.

Section 2 provides definitions for terminology used throughout this
document. Section 3 describes the design goals that lead to the
current autoconfiguration procedure. Section 4 provides an overview
of the protocol, while Section 5 describes the protocol in detail.

2. TERMINOLOGY

   IP - Internet Protocol Version 6. The terms IPv4 and are used
        only in contexts where necessary to avoid ambiguity.

   node - a device that implements IP.

   router - a node that forwards IP packets not explicitly addressed to
        itself.

   host - any node that is not a router.

   upper layer - a protocol layer immediately above IP. Examples are
        transport protocols such as TCP and UDP, control protocols such
        as ICMP, routing protocols such as OSPF, and internet or lower-
        layer protocols being "tunneled" over (i.e., encapsulated in) IP
        such as IPX, AppleTalk, or IP itself.

   link - a communication facility or medium over which nodes can
        communicate at the link layer, i.e., the layer immediately below
        IP. Examples are Ethernets (simple or bridged); PPP links;
        X.25, Frame Relay, or ATM networks; and internet (or higher)
        layer "tunnels", such as tunnels over IPv4 or IPv6 itself.

   interface - a node's attachment to a link.

   packet - an IP header plus payload.

   address - an IP-layer identifier for an interface or a set of
        interfaces.

   unicast address - an identifier for a single interface. A packet sent
        to a unicast address is delivered to the interface identified by
        that address.

   multicast address - an identifier for a set of interfaces (typically
        belonging to different nodes). A packet sent to a multicast
        address is delivered to all interfaces identified by that
        address.

   anycast address - an identifier for a set of interfaces (typically
        belonging to different nodes). A packet sent to an anycast
        address is delivered to one of the interfaces identified by that
        address (the "nearest" one, according to the routing protocol's
        measure of distance). See [ADDR-ARCH].

   solicited-node multicast address - a multicast address to which
        Neighbor Solicitation messages are sent. The algorithm for
        computing the address is given in [DISCOVERY].

   link-layer address - a link-layer identifier for an interface.
        Examples include IEEE 802 addresses for Ethernet links and E.164
        addresses for ISDN links.

   link-local address - an address having link-only scope that can be
        used to reach neighboring nodes attached to the same link. All
        interfaces have a link-local unicast address.

   site-local address - an address having scope that is limited to the
        local site.

   global address - an address with unlimited scope.

   communication - any packet exchange among nodes that requires that
        the address of each node used in the exchange remain the same
        for the duration of the packet exchange. Examples are a TCP
        connection or a UDP request- response.

   tentative address - an address whose uniqueness on a link is being
        verified, prior to its assignment to an interface. A tentative
        address is not considered assigned to an interface in the usual
        sense. An interface discards received packets addressed to a
        tentative address, but accepts Neighbor Discovery packets
        related to Duplicate Address Detection for the tentative
        address.

   preferred address - an address assigned to an interface whose use by
        upper layer protocols is unrestricted. Preferred addresses may
        be used as the source (or destination) address of packets sent
        from (or to) the interface.

deprecated address - An address assigned to an interface whose use is
    discouraged, but not forbidden. A deprecated address should no
    longer be used as a source address in new communications, but
    packets sent from or to deprecated addresses are delivered as
    expected. A deprecated address may continue to be used as a
    source address in communications where switching to a preferred
    address causes hardship to a specific upper-layer activity
    (e.g., an existing TCP connection).

valid address - a preferred or deprecated address. A valid address
    may appear as the source or destination address of a packet, and
    the internet routing system is expected to deliver packets sent
    to a valid address to their intended recipients.

invalid address - an address that is not assigned to any interface. A
    valid address becomes invalid when its valid lifetime expires.
    Invalid addresses should not appear as the destination or source
    address of a packet. In the former case, the internet routing
    system will be unable to deliver the packet, in the later case
    the recipient of the packet will be unable to respond to it.

preferred lifetime - the length of time that a valid address is
    preferred (i.e., the time until deprecation). When the preferred
    lifetime expires, the address becomes deprecated.

valid lifetime - the length of time an address remains in the valid
    state (i.e., the time until invalidation). The valid lifetime
    must be greater then or equal to the preferred lifetime. When
    the valid lifetime expires, the address becomes invalid.

interface identifier - a link-dependent identifier for an interface
    that is (at least) unique per link [ADDR-ARCH]. Stateless
    address autoconfiguration combines an interface identifier with
    a prefix to form an address. From address autoconfiguration's
    perspective, an interface identifier is a bit string of known
    length. The exact length of an interface identifier and the way
    it is created is defined in a separate link-type specific
    document that covers issues related to the transmission of IP
    over a particular link type (e.g., [IPv6-ETHER]). In many
    cases, the identifier will be the same as the interface's link-
    layer address.

2.1. Requirements

The keywords MUST, MUST NOT, REQUIRED, SHALL, SHALL NOT, SHOULD,
SHOULD NOT, RECOMMENDED, MAY, and OPTIONAL, when they appear in this
document, are to be interpreted as described in [KEYWORDS].

3. DESIGN GOALS

   Stateless autoconfiguration is designed with the following goals in
   mind:

      o Manual configuration of individual machines before connecting
        them to the network should not be required. Consequently, a
        mechanism is needed that allows a host to obtain or create
        unique addresses for each of its interfaces. Address
        autoconfiguration assumes that each interface can provide a
        unique identifier for that interface (i.e., an "interface
        identifier"). In the simplest case, an interface identifier
        consists of the interface's link-layer address. An interface
        identifier can be combined with a prefix to form an address.

      o Small sites consisting of a set of machines attached to a single
        link should not require the presence of a stateful server or
        router as a prerequisite for communicating. Plug-and-play
        communication is achieved through the use of link-local
        addresses. Link-local addresses have a well-known prefix that
        identifies the (single) shared link to which a set of nodes
        attach. A host forms a link-local address by appending its
        interface identifier to the link-local prefix.

      o A large site with multiple networks and routers should not
        require the presence of a stateful address configuration server.
        In order to generate site-local or global addresses, hosts must
        determine the prefixes that identify the subnets to which they
        attach. Routers generate periodic Router Advertisements that
        include options listing the set of active prefixes on a link.

      o Address configuration should facilitate the graceful renumbering
        of a site's machines. For example, a site may wish to renumber
        all of its nodes when it switches to a new network service
        provider. Renumbering is achieved through the leasing of
        addresses to interfaces and the assignment of multiple addresses
        to the same interface. Lease lifetimes provide the mechanism
        through which a site phases out old prefixes. The assignment of
        multiple addresses to an interface provides for a transition
        period during which both a new address and the one being phased
        out work simultaneously.

      o System administrators need the ability to specify whether
        stateless autoconfiguration, stateful autoconfiguration, or both
        should be used. Router Advertisements include flags specifying
        which mechanisms a host should use.

4. PROTOCOL OVERVIEW

   This section provides an overview of the typical steps that take
   place when an interface autoconfigures itself. Autoconfiguration is
   performed only on multicast-capable links and begins when a
   multicast-capable interface is enabled, e.g., during system startup.
   Nodes (both hosts and routers) begin the autoconfiguration process by
   generating a link-local address for the interface. A link-local
   address is formed by appending the interface's identifier to the
   well-known link-local prefix.

   Before the link-local address can be assigned to an interface and
   used, however, a node must attempt to verify that this "tentative"
   address is not already in use by another node on the link.
   Specifically, it sends a Neighbor Solicitation message containing the
   tentative address as the target. If another node is already using
   that address, it will return a Neighbor Advertisement saying so. If
   another node is also attempting to use the same address, it will send
   a Neighbor Solicitation for the target as well. The exact number of
   times the Neighbor Solicitation is (re)transmitted and the delay time
   between consecutive solicitations is link-specific and may be set by
   system management.

   If a node determines that its tentative link-local address is not
   unique, autoconfiguration stops and manual configuration of the
   interface is required. To simplify recovery in this case, it should
   be possible for an administrator to supply an alternate interface
   identifier that overrides the default identifier in such a way that
   the autoconfiguration mechanism can then be applied using the new
   (presumably unique) interface identifier. Alternatively, link-local
   and other addresses will need to be configured manually.

   Once a node ascertains that its tentative link-local address is
   unique, it assigns it to the interface. At this point, the node has
   IP-level connectivity with neighboring nodes. The remaining
   autoconfiguration steps are performed only by hosts; the
   (auto)configuration of routers is beyond the scope of this document.

   The next phase of autoconfiguration involves obtaining a Router
   Advertisement or determining that no routers are present. If routers
   are present, they will send Router Advertisements that specify what
   sort of autoconfiguration a host should do. If no routers are
   present, stateful autoconfiguration should be invoked.

   Routers send Router Advertisements periodically, but the delay
   between successive advertisements will generally be longer than a
   host performing autoconfiguration will want to wait [DISCOVERY]. To
   obtain an advertisement quickly, a host sends one or more Router

Solicitations to the all-routers multicast group. Router
Advertisements contain two flags indicating what type of stateful
autoconfiguration (if any) should be performed. A "managed address
configuration" flag indicates whether hosts should use stateful
autoconfiguration to obtain addresses. An "other stateful
configuration" flag indicates whether hosts should use stateful
autoconfiguration to obtain additional information (excluding
addresses).

Router Advertisements also contain zero or more Prefix Information
options that contain information used by stateless address
autoconfiguration to generate site-local and global addresses. It
should be noted that the stateless and stateful address
autoconfiguration fields in Router Advertisements are processed
independently of one another, and a host may use both stateful and
stateless address autoconfiguration simultaneously. One Prefix
Information option field, the "autonomous address-configuration
flag", indicates whether or not the option even applies to stateless
autoconfiguration. If it does, additional option fields contain a
subnet prefix together with lifetime values indicating how long
addresses created from the prefix remain preferred and valid.

Because routers generate Router Advertisements periodically, hosts
will continually receive new advertisements. Hosts process the
information contained in each advertisement as described above,
adding to and refreshing information received in previous
advertisements.

For safety, all addresses must be tested for uniqueness prior to
their assignment to an interface. In the case of addresses created
through stateless autoconfig, however, the uniqueness of an address
is determined primarily by the portion of the address formed from an
interface identifier. Thus, if a node has already verified the
uniqueness of a link-local address, additional addresses created from
the same interface identifier need not be tested individually. In
contrast, all addresses obtained manually or via stateful address
autoconfiguration should be tested for uniqueness individually. To
accommodate sites that believe the overhead of performing Duplicate
Address Detection outweighs its benefits, the use of Duplicate
Address Detection can be disabled through the administrative setting
of a per-interface configuration flag.

To speed the autoconfiguration process, a host may generate its
link-local address (and verify its uniqueness) in parallel with
waiting for a Router Advertisement. Because a router may delay
responding to a Router Solicitation for a few seconds, the total time
needed to complete autoconfiguration can be significantly longer if
the two steps are done serially.

4.1. Site Renumbering

   Address leasing facilitates site renumbering by providing a mechanism
   to time-out addresses assigned to interfaces in hosts. At present,
   upper layer protocols such as TCP provide no support for changing
   end-point addresses while a connection is open. If an end-point
   address becomes invalid, existing connections break and all
   communication to the invalid address fails. Even when applications
   use UDP as a transport protocol, addresses must generally remain the
   same during a packet exchange.

   Dividing valid addresses into preferred and deprecated categories
   provides a way of indicating to upper layers that a valid address may
   become invalid shortly and that future communication using the
   address will fail, should the address's valid lifetime expire before
   communication ends. To avoid this scenario, higher layers should use
   a preferred address (assuming one of sufficient scope exists) to
   increase the likelihood that an address will remain valid for the
   duration of the communication. It is up to system administrators to
   set appropriate prefix lifetimes in order to minimize the impact of
   failed communication when renumbering takes place. The deprecation
   period should be long enough that most, if not all, communications
   are using the new address at the time an address becomes invalid.

   The IP layer is expected to provide a means for upper layers
   (including applications) to select the most appropriate source
   address given a particular destination and possibly other
   constraints. An application may choose to select the source address
   itself before starting a new communication or may leave the address
   unspecified, in which case the upper networking layers will use the
   mechanism provided by the IP layer to choose a suitable address on
   the application's behalf.

   Detailed address selection rules are beyond the scope of this
   document.

5. PROTOCOL SPECIFICATION

   Autoconfiguration is performed on a per-interface basis on
   multicast-capable interfaces. For multihomed hosts,
   autoconfiguration is performed independently on each interface.
   Autoconfiguration applies primarily to hosts, with two exceptions.
   Routers are expected to generate a link-local address using the
   procedure outlined below. In addition, routers perform Duplicate
   Address Detection on all addresses prior to assigning them to an
   interface.

5.1. Node Configuration Variables

   A node MUST allow the following autoconfiguration-related variable to
   be configured by system management for each multicast interface:

   DupAddrDetectTransmits

                    The number of consecutive Neighbor Solicitation
                    messages sent while performing Duplicate Address
                    Detection on a tentative address. A value of zero
                    indicates that Duplicate Address Detection is not
                    performed on tentative addresses. A value of one
                    indicates a single transmission with no follow up
                    retransmissions.

                    Default: 1, but may be overridden by a link-type
                    specific value in the document that covers issues
                    related to the transmission of IP over a particular
                    link type (e.g., [IPv6-ETHER]).

                    Autoconfiguration also assumes the presence of the
                    variable RetransTimer as defined in [DISCOVERY].
                    For autoconfiguration purposes, RetransTimer
                    specifies the delay between consecutive Neighbor
                    Solicitation transmissions performed during
                    Duplicate Address Detection (if
                    DupAddrDetectTransmits is greater than 1), as well
                    as the time a node waits after sending the last
                    Neighbor Solicitation before ending the Duplicate
                    Address Detection process.

5.2. Autoconfiguration-Related Variables

   A host maintains a number of data structures and flags related to
   autoconfiguration. In the following, we present conceptual variables
   and show how they are used to perform autoconfiguration. The specific
   variables are used for demonstration purposes only, and an
   implementation is not required to have them, so long as its external
   behavior is consistent with that described in this document.

   Beyond the formation of a link-local address and using Duplicate
   Address Detection, how routers (auto)configure their interfaces is
   beyond the scope of this document.

   Hosts maintain the following variables on a per-interface basis:

ManagedFlag   Copied from the M flag field (i.e., the
                   "managed address configuration" flag) of the most
                   recently received Router Advertisement message.
                   The flag indicates whether or not addresses are
                   to be configured using the stateful
                   autoconfiguration mechanism. It starts out in a
                   FALSE state.

OtherConfigFlag   Copied from the O flag field (i.e., the "other
                   stateful configuration" flag) of the most
                   recently received Router Advertisement message.
                   The flag indicates whether or not information
                   other than addresses is to be obtained using the
                   stateful autoconfiguration mechanism. It starts
                   out in a FALSE state.

                   In addition, when the value of the ManagedFlag is
                   TRUE, the value of OtherConfigFlag is implicitely
                   TRUE as well. It is not a valid configuration for
                   a host to use stateful address autoconfiguration
                   to request addresses only, without also accepting
                   other configuration
                   information.

   A host also maintains a list of addresses together with their
   corresponding lifetimes. The address list contains both
   autoconfigured addresses and those configured manually.

5.3. Creation of Link-Local Addresses

   A node forms a link-local address whenever an interface becomes
   enabled. An interface may become enabled after any of the
   following
   events:

      - The interface is initialized at system startup time.

      - The interface is reinitialized after a temporary interface
        failure or after being temporarily disabled by system
        management.

      - The interface attaches to a link for the first time.

      - The interface becomes enabled by system management after
        having been administratively
        disabled.

A link-local address is formed by prepending the well-known link-
local prefix FE80::0 [ADDR-ARCH] (of appropriate length) to the
interface identifier. If the interface identifier has a length of N
bits, the interface identifier replaces the right-most N zero bits of
the link-local prefix. If the interface identifier is more than 118
bits in length, autoconfiguration fails and manual configuration is
required. Note that interface identifiers will typically be 64-bits
long and based on EUI-64 identifiers as described in [ADDR-ARCH].

A link-local address has an infinite preferred and valid lifetime; it
is never timed
out.

5.4. Duplicate Address Detection

Duplicate Address Detection is performed on unicast addresses prior
to assigning them to an interface whose DupAddrDetectTransmits
variable is greater than zero. Duplicate Address Detection MUST take
place on all unicast addresses, regardless of whether they are
obtained through stateful, stateless or manual configuration, with
the exception of the following cases:

   - Duplicate Address Detection MUST NOT be performed on anycast
     addresses.

   - Each individual unicast address SHOULD be tested for uniqueness.
     However, when stateless address autoconfiguration is used,
     address uniqueness is determined solely by the interface
     identifier, assuming that subnet prefixes are assigned correctly
     (i.e., if all of an interface's addresses are generated from the
     same identifier, either all addresses or none of them will be
     duplicates). Thus, for a set of addresses formed from the same
     interface identifier, it is sufficient to check that the link-
     local address generated from the identifier is unique on the
     link. In such cases, the link-local address MUST be tested for
     uniqueness, and if no duplicate address is detected, an
     implementation MAY choose to skip Duplicate Address Detection
     for additional addresses derived from the same interface
     identifier.

The procedure for detecting duplicate addresses uses Neighbor
Solicitation and Advertisement messages as described below. If a
duplicate address is discovered during the procedure, the address
cannot be assigned to the interface. If the address is derived from
an interface identifier, a new identifier will need to be assigned to
the interface, or all IP addresses for the interface will need to be
manually configured. Note that the method for detecting duplicates
is not completely reliable, and it is possible that duplicate

addresses will still exist (e.g., if the link was partitioned while
Duplicate Address Detection was performed).

An address on which the duplicate Address Detection Procedure is
applied is said to be tentative until the procedure has completed
successfully. A tentative address is not considered "assigned to an
interface" in the traditional sense. That is, the interface must
accept Neighbor Solicitation and Advertisement messages containing
the tentative address in the Target Address field, but processes such
packets differently from those whose Target Address matches an
address assigned to the interface. Other packets addressed to the
tentative address should be silently discarded.

It should also be noted that Duplicate Address Detection must be
performed prior to assigning an address to an interface in order to
prevent multiple nodes from using the same address simultaneously.
If a node begins using an address in parallel with Duplicate Address
Detection, and another node is already using the address, the node
performing Duplicate Address Detection will erroneously process
traffic intended for the other node, resulting in such possible
negative consequences as the resetting of open TCP connections.

The following subsections describe specific tests a node performs to
verify an address's uniqueness. An address is considered unique if
none of the tests indicate the presence of a duplicate address within
RetransTimer milliseconds after having sent DupAddrDetectTransmits
Neighbor Solicitations. Once an address is determined to be unique,
it may be assigned to an interface.

5.4.1. Message Validation

A node MUST silently discard any Neighbor Solicitation or
Advertisement message that does not pass the validity checks
specified in [DISCOVERY]. A solicitation that passes these validity
checks is called a valid solicitation or valid advertisement.

5.4.2. Sending Neighbor Solicitation Messages

Before sending a Neighbor Solicitation, an interface MUST join the
all-nodes multicast address and the solicited-node multicast address
of the tentative address. The former insures that the node receives
Neighbor Advertisements from other nodes already using the address;
the latter insures that two nodes attempting to use the same address
simultaneously detect each other's presence.

To check an address, a node sends DupAddrDetectTransmits Neighbor
Solicitations, each separated by RetransTimer milliseconds. The
solicitation's Target Address is set to the address being checked,

the IP source is set to the unspecified address and the IP
destination is set to the solicited-node multicast address of the
target address.

If the Neighbor Solicitation is the first message to be sent from an
interface after interface (re)initialization, the node should delay
sending the message by a random delay between 0 and
MAX_RTR_SOLICITATION_DELAY as specified in [DISCOVERY]. This serves
to alleviate congestion when many nodes start up on the link at the
same time, such as after a power failure, and may help to avoid race
conditions when more than one node is trying to solicit for the same
address at the same time. In order to improve the robustness of the
Duplicate Address Detection algorithm, an interface MUST receive and
process datagrams sent to the all-nodes multicast address or
solicited-node multicast address of the tentative address while
delaying transmission of the initial Neighbor Solicitation.

5.4.3. Receiving Neighbor Solicitation Messages

On receipt of a valid Neighbor Solicitation message on an interface,
node behavior depends on whether the target address is tentative or
not. If the target address is not tentative (i.e., it is assigned to
the receiving interface), the solicitation is processed as described
in [DISCOVERY]. If the target address is tentative, and the source
address is a unicast address, the solicitation's sender is performing
address resolution on the target; the solicitation should be silently
ignored. Otherwise, processing takes place as described below. In
all cases, a node MUST NOT respond to a Neighbor Solicitation for a
tentative address.

If the source address of the Neighbor Solicitation is the unspecified
address, the solicitation is from a node performing Duplicate Address
Detection. If the solicitation is from another node, the tentative
address is a duplicate and should not be used (by either node). If
the solicitation is from the node itself (because the node loops back
multicast packets), the solicitation does not indicate the presence
of a duplicate address.

Implementor's Note: many interfaces provide a way for upper layers to
selectively enable and disable the looping back of multicast packets.
The details of how such a facility is implemented may prevent
Duplicate Address Detection from working correctly. See the Appendix
for further discussion.

The following tests identify conditions under which a tentative
address is not unique:

   - If a Neighbor Solicitation for a tentative address is
      received prior to having sent one, the tentative address is a
      duplicate. This condition occurs when two nodes run Duplicate
      Address Detection simultaneously, but transmit initial
      solicitations at different times (e.g., by selecting different
      random delay values before transmitting an initial
      solicitation).

   - If the actual number of Neighbor Solicitations received exceeds
      the number expected based on the loopback semantics (e.g., the
      interface does not loopback packet, yet one or more
      solicitations was received), the tentative address is a
      duplicate. This condition occurs when two nodes run Duplicate
      Address Detection simultaneously and transmit solicitations at
      roughly the same time.

5.4.4. Receiving Neighbor Advertisement Messages

   On receipt of a valid Neighbor Advertisement message on an interface,
   node behavior depends on whether the target address is tentative or
   matches a unicast or anycast address assigned to the interface. If
   the target address is assigned to the receiving interface, the
   solicitation is processed as described in [DISCOVERY]. If the target
   address is tentative, the tentative address is not unique.

5.4.5. When Duplicate Address Detection Fails

   A tentative address that is determined to be a duplicate as described
   above, MUST NOT be assigned to an interface and the node SHOULD log a
   system management error. If the address is a link-local address
   formed from an interface identifier, the interface SHOULD be
   disabled.

5.5. Creation of Global and Site-Local Addresses

   Global and site-local addresses are formed by appending an interface
   identifier to a prefix of appropriate length. Prefixes are obtained
   from Prefix Information options contained in Router Advertisements.
   Creation of global and site-local addresses and configuration of
   other parameters as described in this section SHOULD be locally
   configurable. However, the processing described below MUST be enabled
   by default.

5.5.1. Soliciting Router Advertisements

   Router Advertisements are sent periodically to the all-nodes
   multicast address. To obtain an advertisement quickly, a host sends
   out Router Solicitations as described in [DISCOVERY].

5.5.2. Absence of Router Advertisements

   If a link has no routers, a host MUST attempt to use stateful
   autoconfiguration to obtain addresses and other configuration
   information. An implementation MAY provide a way to disable the
   invocation of stateful autoconfiguration in this case, but the
   default SHOULD be enabled. From the perspective of
   autoconfiguration, a link has no routers if no Router Advertisements
   are received after having sent a small number of Router Solicitations
   as described in [DISCOVERY].

5.5.3. Router Advertisement Processing

   On receipt of a valid Router Advertisement (as defined in
   [DISCOVERY]), a host copies the value of the advertisement's M bit
   into ManagedFlag. If the value of ManagedFlag changes from FALSE to
   TRUE, and the host is not already running the stateful address
   autoconfiguration protocol, the host should invoke the stateful
   address autoconfiguration protocol, requesting both address
   information and other information. If the value of the ManagedFlag
   changes from TRUE to FALSE, the host should continue running the
   stateful address autoconfiguration, i.e., the change in the value of
   the ManagedFlag has no effect. If the value of the flag stays
   unchanged, no special action takes place. In particular, a host MUST
   NOT reinvoke stateful address configuration if it is already
   participating in the stateful protocol as a result of an earlier
   advertisement.

   An advertisement's O flag field is processed in an analogous manner.
   A host copies the value of the O flag into OtherConfigFlag. If the
   value of OtherConfigFlag changes from FALSE to TRUE, the host should
   invoke the stateful autoconfiguration protocol, requesting
   information (excluding addresses if ManagedFlag is set to FALSE). If
   the value of the OtherConfigFlag changes from TRUE to FALSE, the host
   should continue running the stateful address autoconfiguration
   protocol, i.e., the change in the value of OtherConfigFlag has no
   effect. If the value of the flag stays unchanged, no special action
   takes place. In particular, a host MUST NOT reinvoke stateful
   configuration if it is already participating in the stateful protocol
   as a result of an earlier advertisement.

   For each Prefix-Information option in the Router Advertisement:

    a) If the Autonomous flag is not set, silently ignore the
       Prefix Information
       option.

   b) If the prefix is the link-local prefix, silently ignore the
      Prefix Information option.

   c) If the preferred lifetime is greater than the valid lifetime,
      silently ignore the Prefix Information option. A node MAY wish to
      log a system management error in this case.

   d) If the prefix advertised does not match the prefix of an address
      already in the list, and the Valid Lifetime is not 0, form an
      address (and add it to the list) by combining the advertised
      prefix with the link's interface identifier as follows:

```
|              128 - N bits              |        N bits         |
+----------------------------------------+-----------------------+
|              link prefix               |  interface identifier |
+----------------------------------------+-----------------------+
```
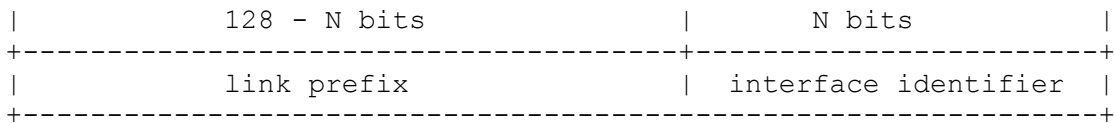
      If the sum of the prefix length and interface identifier length
      does not equal 128 bits, the Prefix Information option MUST be
      ignored. An implementation MAY wish to log a system management
      error in this case. It is the responsibility of the system
      administrator to insure that the lengths of prefixes contained in
      Router Advertisements are consistent with the length of interface
      identifiers for that link type. Note that interface identifiers
      will typically be 64-bits long and based on EUI-64 identifiers as
      described in [ADDR-ARCH].

      If an address is formed successfully, the host adds it to the
      list of addresses assigned to the interface, initializing its
      preferred and valid lifetime values from the Prefix Information
      option.

   e) If the advertised prefix matches the prefix of an autoconfigured
      address (i.e., one obtained via stateless or stateful address
      autoconfiguration) in the list of addresses associated with the
      interface, the specific action to perform depends on the Valid
      Lifetime in the received advertisement and the Lifetime
      associated with the previously autoconfigured address (which we
      call StoredLifetime in the discussion that follows):

      1) If the received Lifetime is greater than 2 hours or greater
         than StoredLifetime, update the stored Lifetime of the
         corresponding address.

      2) If the StoredLifetime is less than or equal to 2 hours and the
         received Lifetime is less than or equal to StoredLifetime,
         ignore the prefix, unless the Router Advertisement from which

this Prefix Information option was obtained has been
authenticated (e.g., via IPSec [RFC2402]). If the Router
Advertisment was authenticated, the StoredLifetime should be
set to the Lifetime in the received option.

3) Otherwise, reset the stored Lifetime in the corresponding
address to two hours.

The above rules address a specific denial of service attack in
which a bogus advertisement could contain prefixes with very
small Valid Lifetimes. Without the above rules, a single
unauthenticated advertisement containing bogus Prefix Information
options with short Lifetimes could cause all of a node's
addresses to expire prematurely. The above rules insure that
legitimate advertisements (which are sent periodically) will
"cancel" the short lifetimes before they actually take effect.

5.5.4. Address Lifetime Expiry

A preferred address becomes deprecated when its preferred lifetime
expires. A deprecated address SHOULD continue to be used as a source
address in existing communications, but SHOULD NOT be used in new
communications if an alternate (non-deprecated) address is available
and has sufficient scope. IP and higher layers (e.g., TCP, UDP) MUST
continue to accept datagrams destined to a deprecated address since a
deprecated address is still a valid address for the interface. An
implementation MAY prevent any new communication from using a
deprecated address, but system management MUST have the ability to
disable such a facility, and the facility MUST be disabled by
default.

An address (and its association with an interface) becomes invalid
when its valid lifetime expires. An invalid address MUST NOT be used
as a source address in outgoing communications and MUST NOT be
recognized as a destination on a receiving interface.

5.6. Configuration Consistency

It is possible for hosts to obtain address information using both
stateless and stateful protocols since both may be enabled at the
same time. It is also possible that the values of other
configuration parameters such as MTU size and hop limit will be
learned from both Router Advertisements and the stateful
autoconfiguration protocol. If the same configuration information is
provided by multiple sources, the value of this information should be
consistent. However, it is not considered a fatal error if
information received from multiple sources is inconsistent. Hosts
accept the union of all information received via the stateless and

stateful protocols. If inconsistent information is learned different
sources, the most recently obtained values always have precedence
over information learned earlier.

6. SECURITY CONSIDERATIONS

    Stateless address autoconfiguration allows a host to connect to a
    network, configure an address and start communicating with other
    nodes without ever registering or authenticating itself with the
    local site. Although this allows unauthorized users to connect to
    and use a network, the threat is inherently present in the
    Internet   architecture. Any node with a physical attachment to
    a network can generate an address (using a variety of ad hoc
    techniques) that provides connectivity.

    The use of Duplicate Address Detection opens up the possibility of
    denial of service attacks. Any node can respond to Neighbor
    Solicitations for a tentative address, causing the other node to
    reject the address as a duplicate. This attack is similar to other
    attacks involving the spoofing of Neighbor Discovery messages and can
    be addressed by requiring that Neighbor Discovery packets be
    authenticated [RFC2402].

7. References

    [RFC2402]   Kent, S. and R. Atkinson, "IP Authentication Header",
                 RFC 2402, November 1998.

    [IPv6-ETHER] Crawford, M., "A Method for the Transmission of
                 IPv6   Packets over Ethernet Networks", RFC 2464,
                 December 1998.

    [KEYWORDS]   Bradner, S., "Key words for use in RFCs to Indicate
                 Requirement Levels", BCP 14, RFC 2119, March
                 1997.

    [RFC1112]   Deering, S., "Host Extensions for IP Multicasting", STD
                 5, RFC 1112, August
                 1989.

    [ADDR-ARCH] Hinden, R. and S. Deering, "Internet Protocol Version
                 (IPv6) Addressing Architecture", RFC 2373, July 1998

    [DHCPv6]   Bound, J. and C. Perkins, "Dynamic Host Configuration
                 Protocol for IPv6 (DHCPv6)", Work in Progress.

   [DISCOVERY]   Narten, T., Nordmark, E. and W. Simpson, "Neighbor
                 Discovery for IP Version 6 (IPv6)", RFC 2461, December
                 1998.

8. Acknowledgements

AUTHORS' ADDRESSES

   Susan Thomson
   Bellcore
   445 South Street
   Morristown, NJ 07960
   USA

   Phone: +1 201-829-4514
   EMail: set@thumper.bellcore.com

   Thomas Narten
   IBM Corporation
   P.O. Box 12195
   Research Triangle Park, NC 27709-2195
   USA

   Phone: +1 919 254 7798
   EMail: narten@raleigh.ibm.com

9.   APPENDIX A: LOOPBACK SUPPRESSION & DUPLICATE ADDRESS DETECTION

   Determining whether a received multicast solicitation was looped back
   to the sender or actually came from another node is implementation-
   dependent. A problematic case occurs when two interfaces attached to
   the same link happen to have the same identifier and link-layer
   address, and they both send out packets with identical contents at
   roughly the same time (e.g., Neighbor Solicitations for a tentative
   address as part of Duplicate Address Detection messages). Although a
   receiver will receive both packets, it cannot determine which packet
   was looped back and which packet came from the other node by simply
   comparing packet contents (i.e., the contents are identical). In this
   particular case, it is not necessary to know precisely which packet
   was looped back and which was sent by another node; if one receives
   more solicitations than were sent, the tentative address is a
   duplicate. However, the situation may not always be this
   straightforward.

   The IPv4 multicast specification [RFC1112] recommends that the
   service interface provide a way for an upper-layer protocol to
   inhibit local delivery of packets sent to a multicast group that the
   sending host is a member of. Some applications know that there will
   be no other group members on the same host, and suppressing loopback
   prevents them from having to receive (and discard) the packets they
   themselves send out. A straightforward way to implement this
   facility is to disable loopback at the hardware level (if supported
   by the hardware), with packets looped back (if requested) by
   software. On interfaces in which the hardware itself suppresses
   loopbacks, a node running Duplicate Address Detection simply counts
   the number of Neighbor Solicitations received for a tentative address
   and compares them with the number expected. If there is a mismatch,
   the tentative address is a duplicate.

   In those cases where the hardware cannot suppress loopbacks, however,
   one possible software heuristic to filter out unwanted loopbacks is
   to discard any received packet whose link-layer source address is the
   same as the receiving interface's. Unfortunately, use of that
   criteria also results in the discarding of all packets sent by
   another node using the same link-layer address. Duplicate Address
   Detection will fail on interfaces that filter received packets in
   this manner:

      o If a node performing Duplicate Address Detection discards
        received packets having the same source link-layer address as
        the receiving interface, it will also discard packets from other
        nodes also using the same link-layer address, including Neighbor
        Advertisement and Neighbor Solicitation messages required to
        make Duplicate Address Detection work correctly. This

particular problem can be avoided by temporarily disabling the
software suppression of loopbacks while a node performs
Duplicate Address Detection.

   o If a node that is already using a particular IP address discards
      received packets having the same link-layer source address as
      the interface, it will also discard Duplicate Address
      Detection-related Neighbor Solicitation messages sent by another
      node also using the same link-layer address. Consequently,
      Duplicate Address Detection will fail, and the other node will
      configure a non-unique address. Since it is generally impossible
      to know when another node is performing Duplicate Address
      Detection, this scenario can be avoided only if software
      suppression of loopback is permanently disabled.

Thus, to perform Duplicate Address Detection correctly in the case
where two interfaces are using the same link-layer address, an
implementation must have a good understanding of the interface's
multicast loopback semantics, and the interface cannot discard
received packets simply because the source link-layer address is the
same as the interfaces.

10.   APPENDIX B: CHANGES SINCE RFC 1971

     o Changed document to use term "interface identifier" rather than
       "interface token" for consistency with other IPv6 documents.

     o Clarified definition of deprecated address to make clear it is OK
       to continue sending to or from deprecated addresses.

     o Reworded section 5.4 for clarity (no substantive change).

     o Added rules to Section 5.5.3 Router Advertisement processing to
       address potential denial-of-service attack when prefixes are
       advertised with very short Lifetimes.

     o Clarified wording in Section 5.5.4 to make clear that all upper
       layer protocols must process (i.e., send and receive) packets sent
       to deprecated addresses.

11. Full Copyright Statement