IPv6 Node Requirements
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Abstract

   This document defines requirements for IPv6 nodes. It is expected
   that IPv6 will be deployed in a wide range of devices and situations.
   Specifying the requirements for IPv6 nodes allows IPv6 to function
   well and interoperate in a large number of situations and
   deployments.

   This document obsoletes RFC 6434, and in turn RFC 4294.

Status of This Memo

   This Internet-Draft is submitted in full conformance with the
   provisions of BCP 78 and BCP 79.

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   time. It is inappropriate to use Internet-Drafts as reference
   material or to cite them other than as "work in progress."

   This Internet-Draft will expire on August 10, 2018.

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1. Introduction

   This document defines common functionality required by both IPv6
   hosts and routers. Many IPv6 nodes will implement optional or
   additional features, but this document collects and summarizes
   requirements from other published Standards Track documents in one
   place.

This document tries to avoid discussion of protocol details and
references RFCs for this purpose. This document is intended to be an
applicability statement and to provide guidance as to which IPv6
specifications should be implemented in the general case and which
specifications may be of interest to specific deployment scenarios.
This document does not update any individual protocol document RFCs.

Although this document points to different specifications, it should
be noted that in many cases, the granularity of a particular
requirement will be smaller than a single specification, as many
specifications define multiple, independent pieces, some of which may
not be mandatory. In addition, most specifications define both
client and server behavior in the same specification, while many
implementations will be focused on only one of those roles.

This document defines a minimal level of requirement needed for a
device to provide useful internet service and considers a broad range
of device types and deployment scenarios. Because of the wide range
of deployment scenarios, the minimal requirements specified in this
document may not be sufficient for all deployment scenarios. It is
perfectly reasonable (and indeed expected) for other profiles to
define additional or stricter requirements appropriate for specific
usage and deployment environments. For example, this document does
not mandate that all clients support DHCP, but some deployment
scenarios may deem it appropriate to make such a requirement. For
example, government agencies in the USA have defined profiles for
specialized requirements for IPv6 in target environments (see
[USGv6]).

As it is not always possible for an implementer to know the exact
usage of IPv6 in a node, an overriding requirement for IPv6 nodes is
that they should adhere to Jon Postel's Robustness Principle: "Be
conservative in what you do, be liberal in what you accept from
others" [RFC0793].

1.1. Scope of This Document

IPv6 covers many specifications. It is intended that IPv6 will be
deployed in many different situations and environments. Therefore,
it is important to develop requirements for IPv6 nodes to ensure
interoperability.

This document assumes that all IPv6 nodes meet the minimum
requirements specified here.

1.2. Description of IPv6 Nodes

   From the Internet Protocol, Version 6 (IPv6) Specification [RFC8200],
   we have the following definitions:

   IPv6 node   - a device that implements IPv6.
   IPv6 router - a node that forwards IPv6 packets not explicitly
                   addressed to itself.
   IPv6 host   - any node that is not a router.

2. Requirements Language

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this
   document are to be interpreted as described in RFC 2119 [RFC2119].

3. Abbreviations Used in This Document

   AH   Authentication Header
   DAD   Duplicate Address Detection
   ESP   Encapsulating Security Payload
   ICMP Internet Control Message Protocol
   IKE   Internet Key Exchange
   MIB   Management Information Base
   MLD   Multicast Listener Discovery
   MTU   Maximum Transmission Unit
   NA   Neighbor Advertisement
   NBMA Non-Broadcast Multiple Access
   ND   Neighbor Discovery
   NS   Neighbor Solicitation
   NUD   Neighbor Unreachability Detection
   PPP   Point-to-Point Protocol

4. Sub-IP Layer

   An IPv6 node must include support for one or more IPv6 link-layer
   specifications. Which link-layer specifications an implementation
   should include will depend upon what link-layers are supported by the
   hardware available on the system. It is possible for a conformant
   IPv6 node to support IPv6 on some of its interfaces and not on
   others.

   As IPv6 is run over new layer 2 technologies, it is expected that new
   specifications will be issued. In the following, we list some of the
   layer 2 technologies for which an IPv6 specification has been
   developed. It is provided for informational purposes only and may
   not be complete.

   - Transmission of IPv6 Packets over Ethernet Networks [RFC2464]

   - Transmission of IPv6 Packets over Frame Relay Networks
      Specification [RFC2590]

   - Transmission of IPv6 Packets over IEEE 1394 Networks [RFC3146]

   - Transmission of IPv6, IPv4, and Address Resolution Protocol (ARP)
      Packets over Fibre Channel [RFC4338]

   - Transmission of IPv6 Packets over IEEE 802.15.4 Networks [RFC4944]

   - Transmission of IPv6 via the IPv6 Convergence Sublayer over IEEE
      802.16 Networks [RFC5121]

   - IP version 6 over PPP [RFC5072]

   In addition to traditional physical link-layers, it is also possible
   to tunnel IPv6 over other protocols. Examples include:

   - Teredo: Tunneling IPv6 over UDP through Network Address
      Translations (NATs) [RFC4380]

   - Section 3 of "Basic Transition Mechanisms for IPv6 Hosts and
      Routers" [RFC4213]

5. IP Layer

5.1. Internet Protocol Version 6 - RFC 8200

   The Internet Protocol Version 6 is specified in [RFC8200]. This
   specification MUST be supported.

   The node MUST follow the packet transmission rules in RFC 8200.

   All conformant IPv6 implementations MUST be capable of sending and
   receiving IPv6 packets; forwarding functionality MAY be supported.
   Nodes MUST always be able to send, receive, and process fragment
   headers. Overlapping fragments MUST be handled as described in
   [RFC5722].

   [RFC6946] discusses IPv6 atomic fragments, and recommends that IPv6
   atomic fragments are processed independently of any other fragments,
   to protect against fragmentation-based attacks. [RFC8021] goes
   further and recommends the deprecation of atomic fragments. Nodes
   thus MUST NOT generate atomic fragments.

To mitigate a variety of potential attacks, nodes SHOULD avoid using
predictable fragment Identification values in Fragment Headers, as
discussed in [RFC7739].

All nodes SHOULD support the setting and use of the IPv6 Flow Label
field as defined in the IPv6 Flow Label specification [RFC6437].
Forwarding nodes such as routers and load distributors MUST NOT
depend only on Flow Label values being uniformly distributed. It is
RECOMMENDED that source hosts support the flow label by setting the
Flow Label field for all packets of a given flow to the same value
chosen from an approximation to a discrete uniform distribution.

5.2. Support for IPv6 Extension Headers

RFC 8200 specifies extension headers and the processing for these
headers.

Any unrecognized extension headers or options MUST be processed as
described in RFC 8200. Note that where Section 4 of RFC 8200 refers
to the action to be taken when a Next Header value in the current
header is not recognized by a node, that action applies whether the
value is an unrecognized Extension Header or an unrecognized upper
layer protocol (ULP).

An IPv6 node MUST be able to process these headers. An exception is
Routing Header type 0 (RH0), which was deprecated by [RFC5095] due to
security concerns and which MUST be treated as an unrecognized
routing type.

Further, [RFC7045] adds specific requirements for processing of
Extension Headers, in particular that any forwarding node along an
IPv6 packet's path, which forwards the packet for any reason, SHOULD
do so regardless of any extension headers that are present.

[RFC7112] discusses issues with oversized IPv6 Extension Header
chains, and states that when a node fragments an IPv6 datagram, it
MUST include the entire IPv6 Header Chain in the First Fragment.

As stated in RFC8200, extension headers (except for the Hop-by-Hop
Options header) are not processed, inserted, or deleted by any node
along a packet's delivery path, until the packet reaches the node (or
each of the set of nodes, in the case of multicast) identified in the
Destination Address field of the IPv6 header.

It should be noted that when future, new Extension Headers are
defined, the consistent format described in Section 4 of [RFC6564]
MUST be followed.

5.3. Protecting a node from excessive EH options

   Per RFC 8200, end hosts are expected to process all extension
   headers, destination options, and hop-by-hop options in a packet.
   Given that the only limit on the number and size of extension headers
   is the MTU, the processing of received packets could be considerable.
   It is also conceivable that a long chain of extension headers might
   be used as a form of denial-of-service attack. Accordingly, a host
   may place limits on the number and sizes of extension headers and
   options it is willing to process.

   A host MAY limit the number of consecutive PAD1 options in
   destination options or hop-by-hop options to seven. In this case, if
   the more than seven consecutive PAD1 options are present the the
   packet should be silently discarded. The rationale is that if
   padding of eight or more bytes is required than the PADN option
   should be used.

   A host MAY limit number of bytes in a PADN option to be less than
   eight. In such a case, if a PADN option is present that has a length
   greater than seven then the packet should be silently discarded. The
   rationale for this guideline is that the purpose of padding is for
   alignment and eight bytes is the maximum alignment used in IPv6.

   A host MAY disallow unknown options in destination options or hop-by-
   hop options. This should be configurable where the default is to
   accept unknown options and process them per [RFC8200]. If a packet
   with unknown options is received and the host is configured to
   disallow them, then the packet should be silently discarded.

   A host MAY impose a limit on the maximum number of non-padding
   options allowed in a destination options and hop-by-hop extension
   headers. If this feature is supported the maximum number should be
   configurable and the default value SHOULD be set to eight. The
   limits for destination options and hop-by-hop options may be
   separately configurable. If a packet is received and the number of
   destination or hop-by-hop optines exceeds the limit, then the packet
   should be silently discarded.

   A host MAY impose a limit on the maximum length of destination
   options or hop-by-hop options extension header. This value should be
   configurable and the default is to accept options of any length. If
   a packet is received and the length of destination or hop-by-hop
   options extension header exceeds the length limit, then the packet
   should be silently discarded.

5.4. Neighbor Discovery for IPv6 - RFC 4861

   Neighbor Discovery is defined in [RFC4861]; the definition was
   updated by [RFC5942]. Neighbor Discovery SHOULD be supported. RFC
   4861 states:

      Unless specified otherwise (in a document that covers operating IP
      over a particular link type) this document applies to all link
      types. However, because ND uses link-layer multicast for some of
      its services, it is possible that on some link types (e.g., Non-
      Broadcast Multi-Access (NBMA) links), alternative protocols or
      mechanisms to implement those services will be specified (in the
      appropriate document covering the operation of IP over a
      particular link type). The services described in this document
      that are not directly dependent on multicast, such as Redirects,
      next-hop determination, Neighbor Unreachability Detection, etc.,
      are expected to be provided as specified in this document. The
      details of how one uses ND on NBMA links are addressed in
      [RFC2491].

   Some detailed analysis of Neighbor Discovery follows:

   Router Discovery is how hosts locate routers that reside on an
   attached link. Hosts MUST support Router Discovery functionality.

   Prefix Discovery is how hosts discover the set of address prefixes
   that define which destinations are on-link for an attached link.
   Hosts MUST support Prefix Discovery.

   Hosts MUST also implement Neighbor Unreachability Detection (NUD) for
   all paths between hosts and neighboring nodes. NUD is not required
   for paths between routers. However, all nodes MUST respond to
   unicast Neighbor Solicitation (NS) messages.

   [RFC7048] discusses NUD, in particular cases where it behaves too
   impatiently. It states that if a node transmits more than a certain
   number of packets, then it SHOULD use the exponential backoff of the
   retransmit timer, up to a certain threshold point.

   Hosts MUST support the sending of Router Solicitations and the
   receiving of Router Advertisements. The ability to understand
   individual Router Advertisement options is dependent on supporting
   the functionality making use of the particular option.

   [RFC7559] discusses packet loss resliency for Router Solicitations,
   and requires that nodes MUST use a specific exponential backoff
   algorithm for RS retransmissions.

All nodes MUST support the sending and receiving of Neighbor
Solicitation (NS) and Neighbor Advertisement (NA) messages. NS and
NA messages are required for Duplicate Address Detection (DAD).

Hosts SHOULD support the processing of Redirect functionality.
Routers MUST support the sending of Redirects, though not necessarily
for every individual packet (e.g., due to rate limiting). Redirects
are only useful on networks supporting hosts. In core networks
dominated by routers, Redirects are typically disabled. The sending
of Redirects SHOULD be disabled by default on backbone routers. They
MAY be enabled by default on routers intended to support hosts on
edge networks.

"IPv6 Host-to-Router Load Sharing" [RFC4311] includes additional
recommendations on how to select from a set of available routers.
[RFC4311] SHOULD be supported.

5.5. SEcure Neighbor Discovery (SEND) - RFC 3971

SEND [RFC3971] and Cryptographically Generated Addresses (CGAs)
[RFC3972] provide a way to secure the message exchanges of Neighbor
Discovery. SEND has the potential to address certain classes of
spoofing attacks, but it does not provide specific protection for
threats from off-link attackers.

There have been relatively few implementations of SEND in common
operating systems and platforms, and thus deployment experience has
been limited to date.

At this time, SEND is considered optional. Due to the complexity in
deploying SEND, and its heavyweight provisioning, its deployment is
only likely to be considered where nodes are operating in a
particularly strict security environment.

5.6. IPv6 Router Advertisement Flags Option - RFC 5175

Router Advertisements include an 8-bit field of single-bit Router
Advertisement flags. The Router Advertisement Flags Option extends
the number of available flag bits by 48 bits. At the time of this
writing, 6 of the original 8 single-bit flags have been assigned,
while 2 remain available for future assignment. No flags have been
defined that make use of the new option, and thus, strictly speaking,
there is no requirement to implement the option today. However,
implementations that are able to pass unrecognized options to a
higher-level entity that may be able to understand them (e.g., a
user-level process using a "raw socket" facility) MAY take steps to
handle the option in anticipation of a future usage.

5.7. Path MTU Discovery and Packet Size

5.7.1. Path MTU Discovery - RFC 8201

"Path MTU Discovery for IP version 6" [RFC8201] SHOULD be supported.
From [RFC8200]:

   It is strongly recommended that IPv6 nodes implement Path MTU
   Discovery [RFC8201], in order to discover and take advantage of
   path MTUs greater than 1280 octets. However, a minimal IPv6
   implementation (e.g., in a boot ROM) may simply restrict itself to
   sending packets no larger than 1280 octets, and omit
   implementation of Path MTU Discovery.

The rules in [RFC8200] and [RFC5722] MUST be followed for packet
fragmentation and reassembly.

One operational issue with Path MTU Discovery occurs when, contrary
to the guidance in [RFC4890], firewalls block ICMP Packet Too Big
messages. Path MTU Discovery relies on such messages to determine
what size messages can be successfully sent. "Packetization Layer
Path MTU Discovery" [RFC4821] avoids having a dependency on Packet
Too Big messages.

5.7.2. Minimum MTU considerations

While an IPv6 link MTU can be set to 1280 bytes, it is recommended
that for IPv6 UDP in particular, which includes DNS operation, the
sender use a large MTU if they can, in order to avoid gratuitous
fragmentation-caused packet drops.

5.8. ICMP for the Internet Protocol Version 6 (IPv6) - RFC 4443

ICMPv6 [RFC4443] MUST be supported. "Extended ICMP to Support Multi-
Part Messages" [RFC4884] MAY be supported.

5.9. Default Router Preferences and More-Specific Routes - RFC 4191

"Default Router Preferences and More-Specific Routes" [RFC4191]
provides support for nodes attached to multiple (different) networks,
each providing routers that advertise themselves as default routers
via Router Advertisements. In some scenarios, one router may provide
connectivity to destinations the other router does not, and choosing
the "wrong" default router can result in reachability failures. In
order to resolve this scenario IPv6 Nodes MUST implement [RFC4191]
and SHOULD implement the Type C host role defined in RFC4191.

5.10. First-Hop Router Selection - RFC 8028

In multihomed scenarios, where a host has more than one prefix, each
allocated by an upstream network that is assumed to implement BCP 38
ingress filtering, the host may have multiple routers to choose from.

Hosts that may be deployed in such multihomed environments SHOULD
follow the guidance given in [RFC8028].

5.11. Multicast Listener Discovery (MLD) for IPv6 - RFC 3810

Nodes that need to join multicast groups MUST support MLDv2
[RFC3810]. MLD is needed by any node that is expected to receive and
process multicast traffic and in particular MLDv2 is required for
support for source-specific multicast (SSM) as per [RFC4607].

Previous versions of this document only required MLDv1 ([RFC2710]) to
be implemented on all nodes. Since participation of any MLDv1-only
nodes on a link require that all other nodeas on the link then
operate in version 1 compatibility mode, the requirement to support
MLDv2 on all nodes was upgraded to a MUST. Further, SSM is now the
preferred multicast distribution method, rather than ASM.

Note that Neighbor Discovery (as used on most link types -- see
Section 5.4) depends on multicast and requires that nodes join
Solicited Node multicast addresses.

5.12. Explicit Congestion Notification (ECN) - RFC 3168

An ECN-aware router may set a mark in the IP header in order to
signal impending congestion, rather than dropping a packet. The
receiver of the packet echoes the congestion indication to the
sender, which can then reduce its transmission rate as if it detected
a dropped packet.

Nodes that may be deployed in environments where they would benefit
from such early congestion notification SHOULD implement [RFC3168].
In such cases, the updates presented in [RFC8311] may also be
relevant.

6. Addressing and Address Configuration

6.1. IP Version 6 Addressing Architecture - RFC 4291

The IPv6 Addressing Architecture [RFC4291] MUST be supported.

The current IPv6 Address Architecture is based on a 64-bit boundary
for subnet prefixes. The reasoning behind this decision is
documented in [RFC7421].

6.2. Host Address Availability Recommendations

Hosts may be configured with addresses through a variety of methods,
including SLAAC, DHCPv6, or manual configuration.

[RFC7934] recommends that networks provide general-purpose end hosts
with multiple global IPv6 addresses when they attach, and it
describes the benefits of and the options for doing so. Router
SHOULD support [RFC7934] for assigning multiple address to a host.
Host SHOULD support assigning multiple addresses as described in
[RFC7934].

Nodes SHOULD support the capability to be assigned a prefix per host
as documented in [RFC8273]. Such an approach can offer improved host
isolation and enhanced subscriber management on shared network
segments.

6.3. IPv6 Stateless Address Autoconfiguration - RFC 4862

Hosts MUST support IPv6 Stateless Address Autoconfiguration. It is
recommended, as described in [RFC8064], that unless there is a
specific requirement for MAC addresses to be embedded in an IID,
nodes follow the procedure in [RFC7217] to generate SLAAC-based
addresses, rather than using [RFC4862]. Addresses generated through
RFC7217 will be the same whenever a given device (re)appears on the
same subnet (with a specific IPv6 prefix), but the IID will vary on
each subnet visited.

Nodes that are routers MUST be able to generate link-local addresses
as described in [RFC4862].

From RFC 4862:

   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.

All nodes MUST implement Duplicate Address Detection. Quoting from
Section 5.4 of RFC 4862:

    Duplicate Address Detection MUST be performed on all unicast
    addresses prior to assigning them to an interface, regardless of
    whether they are obtained through stateless autoconfiguration,
    DHCPv6, or manual configuration, with the following [exceptions
    noted therein].

"Optimistic Duplicate Address Detection (DAD) for IPv6" [RFC4429]
specifies a mechanism to reduce delays associated with generating
addresses via Stateless Address Autoconfiguration [RFC4862]. RFC
4429 was developed in conjunction with Mobile IPv6 in order to reduce
the time needed to acquire and configure addresses as devices quickly
move from one network to another, and it is desirable to minimize
transition delays. For general purpose devices, RFC 4429 remains
optional at this time.

[RFC7527] discusses enhanced DAD, and describes an algorithm to
automate the detection of looped back IPv6 ND messages used by DAD.
Nodes SHOULD implement this behaviour where such detection is
beneficial.

6.4. Privacy Extensions for Address Configuration in IPv6 - RFC 4941

A node using Stateless Address Autoconfiguration [RFC4862] to form a
globally unique IPv6 address using its MAC address to generate the
IID will see that IID remain the same on any visited network, even
though the network prefix part changes. Thus it is possible for 3rd
party devices such nodes communicate with to track the activities of
the node as it moves around the network. Privacy Extensions for
Stateless Address Autoconfiguration [RFC4941] address this concern by
allowing nodes to configure an additional temporary address where the
IID is effectively randomly generated. Privacy addresses are then
used as source addresses for new communications initiated by the
node.

General issues regarding privacy issues for IPv6 addressing are
discussed in [RFC7721].

RFC 4941 SHOULD be supported. In some scenarios, such as dedicated
servers in a data center, it provides limited or no benefit, or may
complicate network management. Thus devices implementing this
specification MUST provide a way for the end user to explicitly
enable or disable the use of such temporary addresses.

Note that RFC4941 can be used independently of traditional SLAAC, or
of RFC7217-based SLAAC.

   Implementers of [RFC 4941](#) should be aware that certain addresses are
   reserved and should not be chosen for use as temporary addresses.
   Consult "Reserved IPv6 Interface Identifiers" [RFC5453] for more
   details.

6.5. Stateful Address Autoconfiguration (DHCPv6) - RFC 3315

   DHCPv6 [RFC3315] can be used to obtain and configure addresses. In
   general, a network may provide for the configuration of addresses
   through SLAAC, DHCPv6, or both. There will be a wide range of IPv6
   deployment models and differences in address assignment requirements,
   some of which may require DHCPv6 for stateful address assignment.
   Consequently, all hosts SHOULD implement address configuration via
   DHCPv6.

   In the absence of observed Router Advertisement messages, IPv6 nodes
   MAY initiate DHCP to obtain IPv6 addresses and other configuration
   information, as described in Section 5.5.2 of [RFC4862].

   Where devices are likely to be carried by users and attached to
   multiple visisted networks, DHCPv6 client anonymity profiles SHOULD
   be supported as described in [RFC7844] to minimise the disclosure of
   identifying information. Section 5 of RFC7844 describes operational
   considerations on the use of such anonymity profiles.

6.6. Default Address Selection for IPv6 - RFC 6724

   IPv6 nodes will invariably have multiple addresses configured
   simultaneously, and thus will need to choose which addresses to use
   for which communications. The rules specified in the Default Address
   Selection for IPv6 [RFC6724] document MUST be implemented. [RFC8028]
   updates rule 5.5 from [RFC6724]; implementations SHOULD implement
   this rule.

7. DNS

   DNS is described in [RFC1034], [RFC1035], [RFC3363], and [RFC3596].
   Not all nodes will need to resolve names; those that will never need
   to resolve DNS names do not need to implement resolver functionality.
   However, the ability to resolve names is a basic infrastructure
   capability on which applications rely, and most nodes will need to
   provide support. All nodes SHOULD implement stub-resolver [RFC1034]
   functionality, as in [RFC1034], Section 5.3.1, with support for:

   - AAAA type Resource Records [RFC3596];

   - reverse addressing in ip6.arpa using PTR records [RFC3596];

   - Extension Mechanisms for DNS (EDNS0) [RFC6891] to allow for DNS
     packet sizes larger than 512 octets.

   Those nodes are RECOMMENDED to support DNS security extensions
   [RFC4033] [RFC4034] [RFC4035].

   A6 Resource Records, which were only ever defined with Experimental
   status in [RFC3363], are now classified as Historic, as per
   [RFC6563].

8. Configuring Non-Address Information

8.1. DHCP for Other Configuration Information

   DHCP [RFC3315] Specifies a mechanism for IPv6 nodes to obtain address
   configuration information (see Section 6.5) and to obtain additional
   (non-address) configuration. If a host implementation supports
   applications or other protocols that require configuration that is
   only available via DHCP, hosts SHOULD implement DHCP. For
   specialized devices on which no such configuration need is present,
   DHCP may not be necessary.

   An IPv6 node can use the subset of DHCP (described in [RFC3736]) to
   obtain other configuration information.

   If an IPv6 node implements DHCP it MUST implement the DNS options
   [RFC3646] as most deployments will expect this options are available.

8.2. Router Advertisements and Default Gateway

   There is no defined DHCPv6 Gateway option.

   Nodes using the Dynamic Host Configuration Protocol for IPv6 (DHCPv6)
   are thus expected to determine their default router information and
   on-link prefix information from received Router Advertisements.

8.3. IPv6 Router Advertisement Options for DNS Configuration - RFC 8106

   Router Advertisement Options have historically been limited to those
   that are critical to basic IPv6 functionality. Originally, DNS
   configuration was not included as an RA option, and DHCP was the
   recommended way to obtain DNS configuration information. Over time,
   the thinking surrounding such an option has evolved. It is now
   generally recognized that few nodes can function adequately without
   having access to a working DNS resolver, and thus a Standards Track
   document has been published to provide this capability [RFC8106].

   Implementations MUST include support for the DNS RA option [RFC8106].

8.4. DHCP Options versus Router Advertisement Options for Host
      Configuration

   In IPv6, there are two main protocol mechanisms for propagating
   configuration information to hosts: Router Advertisements (RAs) and
   DHCP. RA options have been restricted to those deemed essential for
   basic network functioning and for which all nodes are configured with
   exactly the same information. Examples include the Prefix
   Information Options, the MTU option, etc. On the other hand, DHCP
   has generally been preferred for configuration of more general
   parameters and for parameters that may be client-specific. Generally
   speaking, however, there has been a desire to define only one
   mechanism for configuring a given option, rather than defining
   multiple (different) ways of configuring the same information.

   One issue with having multiple ways of configuring the same
   information is that interoperability suffers if a host chooses one
   mechanism but the network operator chooses a different mechanism.
   For "closed" environments, where the network operator has significant
   influence over what devices connect to the network and thus what
   configuration mechanisms they support, the operator may be able to
   ensure that a particular mechanism is supported by all connected
   hosts. In more open environments, however, where arbitrary devices
   may connect (e.g., a WIFI hotspot), problems can arise. To maximize
   interoperability in such environments, hosts would need to implement
   multiple configuration mechanisms to ensure interoperability.

9. Service Discovery Protocols

   [RFC6762] and [RFC6763] describe multicast DNS (mDNS) and DNS-Based
   Service Discovery (DNS-SD) respectively. These protocols,
   collectively commonly referred to as the 'Bonjour' protocols after
   their naming by Apple, provide the means for devices to discover
   services within a local link and, in the absence of a unicast DNS
   service, to exchange naming information.

   Where devices are to be deployed in networks where service dicovery
   would be beneficial, e.g., for users seeking to discover printers or
   display devices, mDNS and DNS-SD SHOULD be supported.

   The IETF dnssd WG is defining solutions for DNS-based service
   discovery in multi-link networks.

10. IPv4 Support and Transition

   IPv6 nodes MAY support IPv4.

10.1. Transition Mechanisms

10.1.1. Basic Transition Mechanisms for IPv6 Hosts and Routers - RFC 4213

If an IPv6 node implements dual stack and tunneling, then [RFC4213] MUST be supported.

11. Application Support

11.1. Textual Representation of IPv6 Addresses - RFC 5952

Software that allows users and operators to input IPv6 addresses in text form SHOULD support "A Recommendation for IPv6 Address Text Representation" [RFC5952].

11.2. Application Programming Interfaces (APIs)

There are a number of IPv6-related APIs. This document does not mandate the use of any, because the choice of API does not directly relate to on-the-wire behavior of protocols. Implementers, however, would be advised to consider providing a common API or reviewing existing APIs for the type of functionality they provide to applications.

"Basic Socket Interface Extensions for IPv6" [RFC3493] provides IPv6 functionality used by typical applications. Implementers should note that RFC3493 has been picked up and further standardized by the Portable Operating System Interface (POSIX) [POSIX].

"Advanced Sockets Application Program Interface (API) for IPv6" [RFC3542] provides access to advanced IPv6 features needed by diagnostic and other more specialized applications.

"IPv6 Socket API for Source Address Selection" [RFC5014] provides facilities that allow an application to override the default Source Address Selection rules of [RFC6724].

"Socket Interface Extensions for Multicast Source Filters" [RFC3678] provides support for expressing source filters on multicast group memberships.

"Extension to Sockets API for Mobile IPv6" [RFC4584] provides application support for accessing and enabling Mobile IPv6 [RFC6275] features.

12. Mobility

   Mobile IPv6 [RFC6275] and associated specifications [RFC3776]
   [RFC4877] allow a node to change its point of attachment within the
   Internet, while maintaining (and using) a permanent address. All
   communication using the permanent address continues to proceed as
   expected even as the node moves around. The definition of Mobile IP
   includes requirements for the following types of nodes:

   - mobile nodes

   - correspondent nodes with support for route optimization

   - home agents

   - all IPv6 routers

   At the present time, Mobile IP has seen only limited implementation
   and no significant deployment, partly because it originally assumed
   an IPv6-only environment rather than a mixed IPv4/IPv6 Internet.
   Recently, additional work has been done to support mobility in mixed-
   mode IPv4 and IPv6 networks [RFC5555].

   More usage and deployment experience is needed with mobility before
   any specific approach can be recommended for broad implementation in
   all hosts and routers. Consequently, [RFC6275], [RFC5555], and
   associated standards such as [RFC4877] are considered a MAY at this
   time.

   IPv6 for 3GPP [RFC7066] lists a snapshot of required IPv6
   Functionalities at the time the document was published that would
   need to be implemented, going above and beyond the recommendations in
   this document. Additionally a 3GPP IPv6 Host MAY implement [RFC7278]
   for delivering IPv6 prefixes on the LAN link.

13. Security

   This section describes the specification for security for IPv6 nodes.

   Achieving security in practice is a complex undertaking. Operational
   procedures, protocols, key distribution mechanisms, certificate
   management approaches, etc., are all components that impact the level
   of security actually achieved in practice. More importantly,
   deficiencies or a poor fit in any one individual component can
   significantly reduce the overall effectiveness of a particular
   security approach.

IPsec either can provide end-to-end security between nodes or or can
provide channel security (for example, via a site-to-site IPsec VPN),
making it possible to provide secure communication for all (or a
subset of) communication flows at the IP layer between pairs of
internet nodes. IPsec has two standard operating modes, Tunnel-mode
and Transport-mode. In Tunnel-mode, IPsec provides network-layer
security and protects an entire IP packet by encapsulating the
orginal IP packet and then pre-pending a new IP header. In
Transport-mode, IPsec provides security for the transport-layer (and
above) by encapsulating only the transport-layer (and above) portion
of the IP packet (i.e., without adding a 2nd IP header).

Although IPsec can be used with manual keying in some cases, such
usage has limited applicability and is not recommended.

A range of security technologies and approaches proliferate today
(e.g., IPsec, Transport Layer Security (TLS), Secure SHell (SSH), SSL
VPNS, etc.) No one approach has emerged as an ideal technology for
all needs and environments. Moreover, IPsec is not viewed as the
ideal security technology in all cases and is unlikely to displace
the others.

Previously, IPv6 mandated implementation of IPsec and recommended the
key management approach of IKE. This document updates that
recommendation by making support of the IPsec Architecture [RFC4301]
a SHOULD for all IPv6 nodes. Note that the IPsec Architecture
requires (e.g., Section 4.5 of RFC 4301) the implementation of both
manual and automatic key management. Currently, the default
automated key management protocol to implement is IKEv2 [RFC7296].

This document recognizes that there exists a range of device types
and environments where approaches to security other than IPsec can be
justified. For example, special-purpose devices may support only a
very limited number or type of applications, and an application-
specific security approach may be sufficient for limited management
or configuration capabilities. Alternatively, some devices may run
on extremely constrained hardware (e.g., sensors) where the full
IPsec Architecture is not justified.

Because most common platforms now support IPv6 and have it enabled by
default, IPv6 security is an issue for networks that are ostensibly
IPv4-only; see [RFC7123] for guidance on this area.

13.1. Requirements

"Security Architecture for the Internet Protocol" [RFC4301] SHOULD be
supported by all IPv6 nodes. Note that the IPsec Architecture
requires (e.g., Section 4.5 of [RFC4301]) the implementation of both

manual and automatic key management. Currently, the default
automated key management protocol to implement is IKEv2. As required
in [RFC4301], IPv6 nodes implementing the IPsec Architecture MUST
implement ESP [RFC4303] and MAY implement AH [RFC4302].

13.2. Transforms and Algorithms

The current set of mandatory-to-implement algorithms for the IPsec
Architecture are defined in "Cryptographic Algorithm Implementation
Requirements For ESP and AH" [RFC8221]. IPv6 nodes implementing the
IPsec Architecture MUST conform to the requirements in [RFC8221].
Preferred cryptographic algorithms often change more frequently than
security protocols. Therefore, implementations MUST allow for
migration to new algorithms, as RFC 8221 is replaced or updated in
the future.

The current set of mandatory-to-implement algorithms for IKEv2 are
defined in "Cryptographic Algorithms for Use in the Internet Key
Exchange Version 2 (IKEv2)" [RFC8247]. IPv6 nodes implementing IKEv2
MUST conform to the requirements in [RFC8247] and/or any future
updates or replacements to [RFC8247].

14. Router-Specific Functionality

This section defines general host considerations for IPv6 nodes that
act as routers. Currently, this section does not discuss detailed
routing-specific requirements. For the case of typical home routers,
[RFC7084] defines basic requirements for customer edge routers.

Further recommendations on router-specific functionality can be found
in [I-D.ietf-v6ops-ipv6rtr-reqs].

14.1. IPv6 Router Alert Option - RFC 2711

The IPv6 Router Alert Option [RFC2711] is an optional IPv6 Hop-by-Hop
Header that is used in conjunction with some protocols (e.g., RSVP
[RFC2205] or Multicast Listener Discovery (MLDv2) [RFC3810]). The
Router Alert option will need to be implemented whenever such
protocols that mandate its use are implemented. See Section 5.11.

14.2. Neighbor Discovery for IPv6 - RFC 4861

Sending Router Advertisements and processing Router Solicitations
MUST be supported.

Section 7 of [RFC6275] includes some mobility-specific extensions to
Neighbor Discovery. Routers SHOULD implement Sections 7.3 and 7.5,
even if they do not implement Home Agent functionality.

14.3. **Stateful Address Autoconfiguration (DHCPv6) - RFC 3315**

   A single DHCP server ([RFC3315] or [RFC4862]) can provide
   configuration information to devices directly attached to a shared
   link, as well as to devices located elsewhere within a site.
   Communication between a client and a DHCP server located on different
   links requires the use of DHCP relay agents on routers.

   In simple deployments, consisting of a single router and either a
   single LAN or multiple LANs attached to the single router, together
   with a WAN connection, a DHCP server embedded within the router is
   one common deployment scenario (e.g., [RFC7084]). There is no need
   for relay agents in such scenarios.

   In more complex deployment scenarios, such as within enterprise or
   service provider networks, the use of DHCP requires some level of
   configuration, in order to configure relay agents, DHCP servers, etc.
   In such environments, the DHCP server might even be run on a
   traditional server, rather than as part of a router.

   Because of the wide range of deployment scenarios, support for DHCP
   server functionality on routers is optional. However, routers
   targeted for deployment within more complex scenarios (as described
   above) SHOULD support relay agent functionality. Note that "Basic
   Requirements for IPv6 Customer Edge Routers" [RFC7084] requires
   implementation of a DHCPv6 server function in IPv6 Customer Edge (CE)
   routers.

14.4. **IPv6 Prefix Length Recommendation for Forwarding - BCP 198**

   Forwarding nodes MUST conform to BCP 198 [RFC7608] and thus IPv6
   implementations of nodes that may forward packets MUST conform to the
   rules specified in Section 5.1 of [RFC4632].

15. **Constrained Devices**

   The target for this document is general IPv6 nodes. In the case of
   constrained nodes, with limited CPU, memory, bandwidth or power,
   support for certain IPv6 functionality may need to be considered due
   to those limitations. The requirements of this document are
   RECOMMENDED for all nodes, including constrained nodes, but
   compromises may need to be made in certain cases. Where such
   compromises are made, the interoperability of devices should be
   strongly considered, paticularly where this may impact other nodes on
   the same link, e.g., only supporting MLDv1 will affect other nodes.

   The IETF 6LowPAN (IPv6 over Low Power LWPAN) WG defined six RFCs,
   including a general overview and problem statement ([RFC4919], the

means by which IPv6 packets are transmitted over IEEE 802.15.4
networks [RFC4944] and ND optimisations for that medium [RFC6775].

If an IPv6 node is concerned about the impact of IPv6 message power
consumption, it SHOULD want to implement the recommendations in
[RFC7772].

16. Network Management

Network management MAY be supported by IPv6 nodes. However, for IPv6
nodes that are embedded devices, network management may be the only
possible way of controlling these nodes.

A node supporting network management SHOULD support NETCONF [RFC6241]
and SNMP configuration [RFC3411].

16.1. Management Information Base (MIB) Modules

IPv6 MIBs have been updated since the last release of the document;
[RFC8096] obseletes several MIBs, which nodes need no longer support.

The following two MIB modules SHOULD be supported by nodes that
support a Simple Network Management Protocol (SNMP) agent.

16.1.1. IP Forwarding Table MIB

The IP Forwarding Table MIB [RFC4292] SHOULD be supported by nodes
that support an SNMP agent.

16.1.2. Management Information Base for the Internet Protocol (IP)

The IP MIB [RFC4293] SHOULD be supported by nodes that support an
SNMP agent.

16.2. YANG Data Models

The following YANG data models SHOULD be supported by nodes that
support a NETCONF agent.

16.2.1. IP Management YANG Model

The IP Management YANG Model [RFC7277] SHOULD be supported by nodes
that support NETCONF.

16.2.2. **System Management YANG Model**

   The System Management YANG Model [RFC7317] SHOULD be supported by
   nodes that support NETCONF.

16.2.3. **System Management YANG Model**

   The Interface Management YANG Model [RFC7223] SHOULD be supported by
   nodes that support NETCONF.

17. **Security Considerations**

   This document does not directly affect the security of the Internet,
   beyond the security considerations associated with the individual
   protocols.

   Security is also discussed in Section 13 above.

18. **IANA Considerations**

   This document does not require any IANA actions.

19. **Authors and Acknowledgments**

19.1. **Authors and Acknowledgments (Current Document)**

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20. Appendix: Changes from RFC 6434

   There have been many editorial clarifications as well as significant
   additions and updates. While this section highlights some of the
   changes, readers should not rely on this section for a comprehensive
   list of all changes.

   1.   Restructured sections

   2.   Added 6LoWPAN to link layers as it has some deployment.

   3.   Removed DOD IPv6 Profile as it hasn't been updated.

   4.   Updated to MLDv2 support to a MUST since nodes are restricted if
         MLDv1 is used.

   5.   Require DNS RA Options so SLAAC-only devices can get DNS,
         RFC8106 is a MUST.

   6.   Require RFC3646 DNS Options for DHCPv6 implementations.

   7.   Added section on constrained devices.

   8.   Added text on RFC7934, address availability to hosts (SHOULD).

   9.   Added text on RFC7844, anonymity profiles for DHCPv6 clients.

   10.   mDNS and DNS-SD added as updated service discovery.

   11.   Added RFC8028 as a SHOULD as a method for solving multi-prefix
         network

   12.   Added ECN RFC3168 as a SHOULD, since recent reports have shown
         this as useful, and added a note on RFC8311, which is related.

   13.   Added reference to RFC7123 for Security over IPv4-only networks

   14.   Removed Jumbograms RFC2675 as they aren't deployed.

   15.   Updated Obseleted RFCs to the new version of the RFC including
         2460, 1981, 7321, 4307

   16.   Added RFC7772 for power comsumptions considerations

   17.   Added why /64 boundries for more detail - RFC 7421

   18.   Added a Unique IPv6 Prefix per Host to support currently
         deployed IPv6 networks

   19. Clarified RFC7066 was snapshot for 3GPP

   20. Updated 4191 as a MUST, SHOULD for Type C Host as it helps solve
        multi-prefix problem

   21. Removed IPv6 over ATM since there aren't many deployments

   22. Added a note in Section 6.6 for RFC6724 Section 5.5/

   23. Added MUST for BCP 198 for forwarding IPv6 packets

   24. Added reference to draft-ietf-v6ops-ipv6rtr-reqs as it has more
        recommendations for a Router

   25. Added reference to RFC8064 for stable address creation.

   26. Added text on protection from excessive EH options

   27. Added text on dangers of 1280 MTU UDP, esp. wrt DNS traffic

   28. Added text to clarify RFC8200 behaviour for unrecognized EHs or
        unrecognized ULPs

21. Appendix: Changes from RFC 4294

   There have been many editorial clarifications as well as significant
   additions and updates. While this section highlights some of the
   changes, readers should not rely on this section for a comprehensive
   list of all changes.

   1.   Updated the Introduction to indicate that this document is an
        applicability statement and is aimed at general nodes.

   2.   Significantly updated the section on Mobility protocols, adding
        references and downgrading previous SHOULDs to MAYs.

   3.   Changed Sub-IP Layer section to just list relevant RFCs, and
        added some more RFCs.

   4.   Added section on SEND (it is a MAY).

   5.   Revised section on Privacy Extensions [RFC4941] to add more
        nuance to recommendation.

   6.   Completely revised IPsec/IKEv2 section, downgrading overall
        recommendation to a SHOULD.

   7.   Upgraded recommendation of DHCPv6 to SHOULD.

8.   Added background section on DHCP versus RA options, added SHOULD
      recommendation for DNS configuration via RAs ([RFC6106]), and
      cleaned up DHCP recommendations.

9.   Added recommendation that routers implement Sections 7.3 and 7.5
      of [RFC6275].

10.   Added pointer to subnet clarification document [RFC5942].

11.   Added text that "IPv6 Host-to-Router Load Sharing" [RFC4311]
      SHOULD be implemented.

12.   Added reference to [RFC5722] (Overlapping Fragments), and made
      it a MUST to implement.

13.   Made "A Recommendation for IPv6 Address Text Representation"
      [RFC5952] a SHOULD.

14.   Removed mention of "DNAME" from the discussion about [RFC3363].

15.   Numerous updates to reflect newer versions of IPv6 documents,
      including [RFC4443], [RFC4291], [RFC3596], and [RFC4213].

16.   Removed discussion of "Managed" and "Other" flags in RAs. There
      is no consensus at present on how to process these flags, and
      discussion of their semantics was removed in the most recent
      update of Stateless Address Autoconfiguration [RFC4862].

17.   Added many more references to optional IPv6 documents.

18.   Made "A Recommendation for IPv6 Address Text Representation"
      [RFC5952] a SHOULD.

19.   Added reference to [RFC5722] (Overlapping Fragments), and made
      it a MUST to implement.

20.   Updated MLD section to include reference to Lightweight MLD
      [RFC5790].

21.   Added SHOULD recommendation for "Default Router Preferences and
      More-Specific Routes" [RFC4191].

22.   Made "IPv6 Flow Label Specification" [RFC6437] a SHOULD.

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