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Automatically Connecting Stub Networks to Unmanaged Infrastructure
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Abstract

This document describes a set of practices for connecting stub networks to adjacent infrastructure networks. This is applicable in cases such as constrained (Internet of Things) networks where there is a need to provide functional parity of service discovery and reachability between devices on the stub network and devices on an adjacent infrastructure link (for example, a home network).

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1. Introduction

This document describes a set of practices for automatically connecting IPv6 stub networks to adjacent infrastructure networks. The connection is enabled through a Stub Network Auto-Configuring router, or SNAC router. There are several use cases for stub networks. Motivating factors include:

- * Incompatible speed: for example, an IEEE 802.15.4 network could not be easily bridged to a Wi-Fi network because the data rates are so dissimilar. So either it must be bridged in a very complicated and careful way to avoid overwhelming the 802.15.4 network with irrelevant traffic, or the 802.15.4 network needs to be a separate subnet.
- * Incompatible media: for example, a constrained 802.15.4 network connected as a stub network to a Wi-Fi or ethernet infrastructure network. In the case of an 802.15.4 network, it is quite possible that the devices used to link the infrastructure network to the stub network will not be conceived of by the end user as routers. Consequently, one cannot assume that these devices will be on all the time. A solution for this use case will require some sort of commissioning process for stub routers, and can't assume that any particular stub router will always be available; rather, any stub router that is available must be able to adapt to current conditions to provide reachability.

- * Incompatible mechanisms: the medium of the stub network may not, for example, use IPv6 neighbor discovery to populate a neighbor cache. If the infrastructure network (as is typical) does use neighbor discovery, then bridging the two networks together would require some way of translating between neighbor discovery and whatever mechanism is used on the stub network, and hence complicates rather than simplifying the problem of connecting the two networks.
- * Incompatible framing: if the stub network is a 6lowpan [RFC4944] network, packets on the stub network are expected to use 6lowpan header compression [RFC6282]. Making this work through a bridge would be very difficult.
- * Convenience: end users often connect devices to each other in order to extend networks
- * Transitory connectivity: a mobile device acting as a router for a set of co-located devices could connect to a network and gain access to services for itself and for the co-located devices. Such a stub network is unlikely to have more than one stub router.

What makes stub networks a distinct type of network is simply that a stub network never provides transit between networks to which it is connected. The term "stub" refers to the way the network is seen by the link to which it is connected: there is reachability through a stub network router to devices on the stub network from the infrastructure link, but there is no reachability through the stub network to any link beyond that one.

Eliminating transit routing is not intended to be seen as a virtue in itself, but rather as a simplifying assumption that makes it possible to solve a subset of the general problem of automating multi-link networks. Stub networks may be globally reachable, or may be only locally reachable. A host on a locally reachable stub network can only interoperate with hosts on the network link(s) to which it is connected. A host on a globally reachable stub network should be able to interoperate with hosts on other network links in the same infrastructure as well as hosts on the global internet.

It may be noted that just as one can plug several CE Router devices together in series to form multi-layer NATs, there is nothing preventing the owner of a stub network router from attaching it to a stub network as if that network were its infrastructure network. In the case of an IoT wireless network, there may be no way to do this, nor would it be desirable, but a stub router that uses ethernet on both the infrastructure and stub network sides could be connected this way. Nothing in this document is intended to prevent this from being done, but neither does this document attempt to solve the problems that this could create.

The goal of this document is to describe the minimal set of changes or behaviors required to use existing IETF specifications to support the stub network use case. The result is intended to be deployable on existing networks without requiring changes to those networks.

1.1. Interoperability Goals

The specific goal is for hosts on the stub network to be able to interoperate with hosts on the adjacent infrastructure link or links. What is meant by "interoperate" is that a host on a stub network:

- * is discoverable by hosts attached to adjacent infrastructure links
- * is able to discover hosts attached to adjacent infrastructure links
- * is able to discover hosts on the Internet
- * is able to acquire an IP address that can be used to communicate with hosts attached to adjacent infrastructure links
- * has reachability to the hosts attached to adjacent infrastructure links
- * is reachable by hosts on the adjacent infrastructure link
- * is able to reach hosts on the Internet

Discoverability here means "discoverable using DNS, or DNS Service Discovery". DNS Service Discovery includes multicast DNS [RFC6762]. As an example, when one host connected to a specific Wi-Fi network wishes to discover services on hosts connected to that same Wi-Fi network, it can do so using multicast DNS. Similarly, when a host on some other network wishes to discover the same service, it must use DNS-based DNS Service Discovery [RFC6763]. In both cases, "discoverable using DNS" means that the host has one or more entries in the DNS that serve to make it discoverable.

Discoverability is lumped in with reachability and addressability, both of which are essentially Layer 3 issues. The reason for this is that it does no good to automatically set up connectivity between stub network hosts and infrastructure hosts if the infrastructure hosts have no means to learn about the availability of services provided by stub network hosts. For stub network hosts that only consume cloud services this will not be an issue, but for stub networks that provide services, such as IoT devices on stub networks with incompatible media, discoverability is necessary in order for stub network connectivity to be useful.

Ability to acquire an IP address that can be used to communicate means that the IP address a host on the stub network acquires can be used to communicate with it by hosts not on the stub network.

Reachability to hosts on adjacent infrastructure links means that when a host (A) on the stub network has a datagram destined for the IP address of a host (B) on an adjacent infrastructure link, host (A) knows of a next-hop router to which it can send the datagram, so that it will ultimately reach host (B) on the infrastructure network.

Reachability from hosts on adjacent infrastructure links means that when host (A) on an adjacent infrastructure link has a datagram destined for the IP address of a host (B) on the stub network, a next-hop router is known by host (A) such that, when the datagram is sent to that router, it will ultimately reach host (B) on the stub network.

To achieve the reachability goal described above, this document assumes hosts attempting to reach destinations on the stub network maintain a routing table - Type C hosts as defined in Section 3.1 of [RFC4191]). Type A and Type B hosts are out-of-scope for this document.

1.2. Usability Goals

In addition to the interoperability goals described above, the additional goal for stub networks is that these be able to be connected automatically, with no user intervention. The experience of connecting a stub network to an infrastructure network should be as straightforward as connecting a new host to the same infrastructure network.

SNAC routers can be attached to any network. However, there are network configurations where a SNAC router will not work. An analysis of networks where SNAC routers could be attached is provided in Appendix A.

1.3. Sample SNAC Router Aware Infrastructure Network

A Stub network attached via SNAC routers the infrastructure network. The Infrastructure router with in the scope of this specification is an IPv6 (aware) router and provides different services in the network. These routers can be a CE, home gateway or a WiFi router. A SNAC router will connect as any another device in the infrastructure network, additionally providing addressability, discoverability and reachability functions for devices in the stub network.

This document describes mechanisms for connecting devices in Stub networks to the infrastructure using SNAC router as shown in Figure 1. Although the use case described below is specific to home networks, the procedures apply for any type of infrastructure and stub network attachment scenarios.

A SNAC router receives and manages suitable IPV6 prefix on AIL preferably from the infrastructure router or from other SNAC routers in the network. In case addressing is not available, SNAC router provides and advertises it on the AIL.

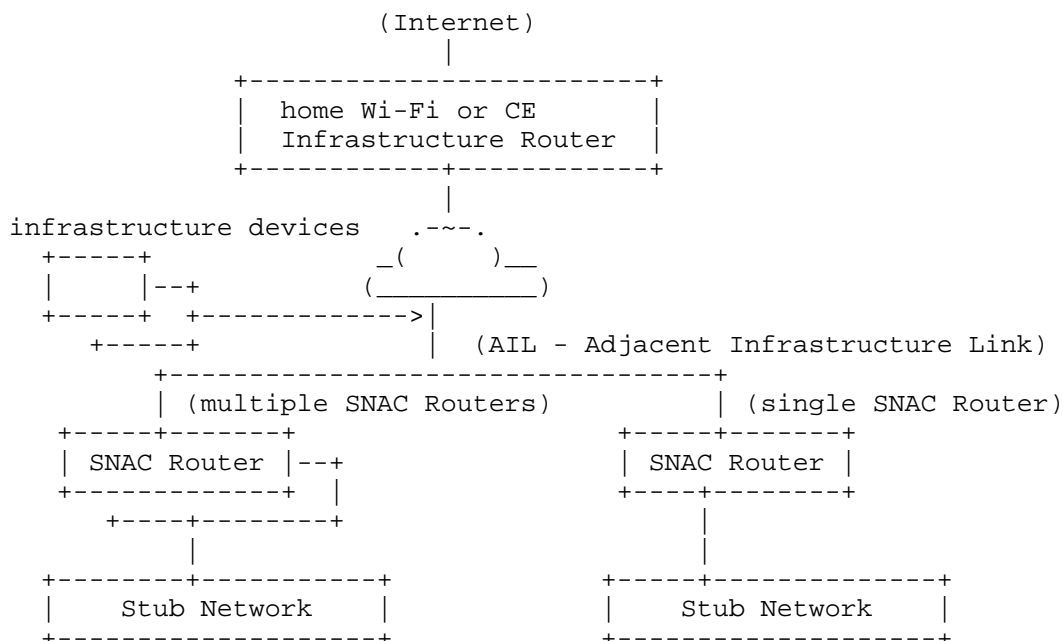


Figure 1: SNAC Router connecting Stub Networks to Infrastructure

2. Glossary

Node: A device that implements IPv6.

Router: A node that forwards IPv6 packets not explicitly addressed to itself. (See Note in Section 2 of [RFC8200].)

Host: Any node that is not a router. (See Note in Section 2 of [RFC8200].)

Addressability: The ability to associate each node on a link with its own IPv6 address.

Reachability: Given an IPv6 destination address that is not on-link for any link to which a node is attached, the information required that allows the node to send packets to a router that can forward those packets towards a link where the destination address is on-link.

Adjacent Infrastructure Link (AIL): any link to which a stub network router is directly attached, that is part of an infrastructure network and is not the stub network.

Customer Edge (CE) Router: CE Router is defined in [RFC7084]. A CE router is a device that is intended to connect a single uplink network to a Local-Area Network. A CE router may be provided by an ISP and only capable of connecting directly to the ISP's means of service delivery, e.g. Cable or DSL, or it may have an ethernet port on the WAN side and one or more ethernet ports, plus WiFi, on the LAN side.

Infrastructure network: the network infrastructure to which a stub router connects. This network can be a single link, or a network of links. The network is typically formed by a CE router, which may also provide some services, such as a DNS resolver, a DHCPv4 server, and a DHCPv6 prefix delegation server, for example.

Off-Stub-Network-Routable (OSNR) Prefix: a prefix advertised on the stub network that can be used for communication with hosts not on the stub network.

Stub Network: A network link that is connected by one or more stub routers to an AIL in an infrastructure network, but is not used for transit between that link and any other link. Section 2.1 of [RFC2328] describes the distinction between stub networks and transit networks from a topological perspective: a stub network is

simply any network that does not provide transit within a routing fabric. There is reachability through a stub network router to hosts on the stub network, but there is no reachability through the stub network to any link beyond the stub network link.

Stub Router: A router that provides connectivity between a stub network and an infrastructure network. A stub router may also provide connectivity between other networks: the term "stub router" refers specifically to its role in providing connectivity to a stub network. For example, a CE Router may provide connectivity between a provider network (WAN) and a network (LAN), while at the same time providing connectivity between the LAN and a stub network. What distinguishes the LAN from the stub network in this case is that the LAN is potentially a candidate to act as a transit network to reach other routers, whereas the stub network is not.

SNAC Router: A Stub Network Auto-Configuring (SNAC) Router. This is a stub router that implements the autoconfiguration methods defined by this specification. By definition, a CE router can't be a SNAC router, because it is an infrastructure router, and therefore has operational control over its stub networks.

ULA Site Prefix: A Unique Local Address /48 prefix [RFC4193] randomly generated by each SNAC router for use in allocating ULA link prefixes to the stub network and the adjacent infrastructure link.

ULA Link Prefix: A Unique Local Address /64 prefix allocated from the ULA site prefix. SNAC routers can use ULA Link prefixes to provide addressability on the stub network and/or adjacent infrastructure link as needed. If a SNAC router is doing NAT64, the NAT64 prefix is also a ULA link prefix. A total of 65,536 ULA link prefixes can be allocated from the ULA site prefix.

3. Constants

This section describes the meaning of and gives default values for various constants used in this document.

STALE_RA_TIME (default: 10 minutes): The amount of time that can

pass after the last time a Router Advertisement (RA) message from a particular router has been received before it is assumed the router is no longer present. This is a stopgap in case the router is reachable but has silently stopped advertising a prefix; this situation is unlikely, but if it does happen, new devices joining the infrastructure network will not be able to reach devices on the stub network until the SNAC router decides that the router that advertised the suitable prefix is stale.

STUB_PROVIDED_PREFIX_LIFETIME (default: 30 minutes): The valid and preferred lifetime the SNAC router will advertise for a prefix on the AIL. This should be long enough that a host is actually willing to use it, and obviously should also be long enough that a missed RA will not cause the host to stop using it. The values suggested here allow ten RAs to be missed before the host will stop using the prefix.

MinRtrAdvInterval (default: 154 seconds): The minimum interval for periodic unsolicited RA message sending (as defined in [RFC4861]) for a SNAC router. This determines together with **MaxRtrAdvInterval** how often the SNAC router will transmit these multicast RA messages. This should be frequent enough that a missed Router Solicitation (RS) message (e.g. due to congestion on a WiFi link) will not result in an extremely long outage (assuming the congestion passes before the RA is sent, of course). The default values defined here lead to an RA multicast every 3 minutes, on average.

MaxRtrAdvInterval (default: 206 seconds): The maximum interval for periodic unsolicited RA message sending (as defined in [RFC4861]) for a SNAC router.

MIN_PD_PREFIX_LIFETIME (default: 30 minutes): The minimum preferred lifetime that a prefix, delegated with DHCPv6-PD, must have in order to be suitable as a OSNR prefix for the stub network. The minimum lifetime is chosen to be long enough that a reboot of the DHCP server or the SNAC router will not prevent the successful renewal of the prefix.

MAX_SUITABLE_REACHABLE_TIME (default: 60 seconds): The maximum ReachableTime value that a router can have in the neighbor cache before any suitable prefixes it has advertised are no longer considered suitable.

STUB_NETWORK_ROUTE_LIFETIME (default: 30 minutes) The Route Lifetime

that will be specified in Route Information Options sent by the SNAC router to advertise the route to its stub network on the AIL. Also, the maximum Route Lifetime that will be specified in Route Information Options sent by the SNAC router to its stub network to advertise the route to the AIL.

MIN_SUITABLE_PREFIX_PREFERRED_LIFETIME (default: 30 minutes): The minimum preferred lifetime required for an AIL prefix to be considered suitable for use by SNAC routers. This value ensures that prefixes have sufficient lifetime to be reliably used for address autoconfiguration and communication establishment.

4. Conventions and Terminology Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

5. Support for adjacent infrastructure links

This document assumes that the AIL supports neighbor discovery [RFC4861], and specifically that routers and on-link prefixes can be advertised using Router Advertisement messages and discovered using Neighbor Solicitation messages. The stub network link may also support this, or may use some different mechanism. This section specifies how advertisement of the on-link prefix for such links is managed. In this section the term "advertising interface" is used as defined in Section 6.2.2 of [RFC4861].

Support for AILs on networks where neighbor discovery is not supported is out of scope for this document. SNAC routers do not provide routing between AILs when connected to more than one such link.

5.1. Managing addressability on an adjacent infrastructure link

In order to provide IPv6 routing to the stub network, IPv6 addressing must be available on each AIL. Ideally such addressing is already present on these links, and need not be provided. However, if it is not present, the SNAC router must provide it.

5.1.1. Suitable On-Link Prefixes

SNAC routers must evaluate prefixes that are advertised on-link as to their suitability for use in communicating with devices on the stub network. If no suitable prefix is found, a SNAC router MUST advertise one.

An on-link prefix is considered suitable if it is advertised on the link in a Prefix Information option ([RFC4861], Section 4.6.2) with the following Prefix Information option header values:

- * Prefix Length is 64, suitable for IPv6 Stateless Address Autoconfiguration (SLAAC), consistent with current implementations and Section 2.5.1 of [RFC4291] 64bit Interface Identifiers
- * 'L' flag bit is set and
- * either the 'A' flag bit or the 'P' flag bit [I-D.ietf-6man-pio-pflag] is set, and
- * Preferred Lifetime of MIN_SUITABLE_PREFIX_PREFERRED_LIFETIME or more.

A prefix is not considered a suitable on-link prefix if the 'L' flag bit is not set, or if neither the 'A' flag bit nor the 'P' flag bit is set. When the 'A' flag bit is not set, this indicates that individual node addresses cannot be configured with SLAAC. In this case, typically addresses are managed using DHCPv6, or (in rare cases) another method. If the 'P' flag bit is set, then hosts that wish to allocate their own addresses can do so by acquiring a prefix from which to allocate them using DHCPv6 prefix delegation [RFC9663]. Nodes are not required to use DHCPv6 to acquire individual addresses, so a prefix that requires the use of DHCPv6 for that purpose can't be considered "suitable"—not all hosts can actually use it.

Note: there can be layer two networks where neighbor discovery is not supported and therefore the 'L' flag bit cannot be set, while the 'A' flag bit could be set. The behavior of SNAC routers when connecting to such networks is out of scope for this document.

A prefix is considered to be advertised on the link if, when a Router Solicitation message ([RFC4861], Section 4.1) is sent, a Router Advertisement message is received in response which contains a prefix information option ([RFC4861], Section 4.6.2) for that prefix.

After an RA message containing a suitable prefix has been received, it can be assumed for some period of time thereafter that that prefix is still valid on the link. However, prefix lifetimes and router

lifetimes are often quite long. In addition to knowing that a prefix has been advertised on the link in the past, and is still valid, it must therefore be ensured that at least one router that has advertised this prefix is still alive to respond to Router Advertisement messages.

5.1.2. State Machine for maintaining a suitable on-link prefix on an infrastructure link

The possible states of an interface connected to an AIL are described here, along with actions required to be taken to monitor the state. The purpose of the state machine described here is to ensure that at all times, when a new host arrives on the AIL, it is able to acquire an IPv6 address on that link.

During all of the states mentioned here except for state-unknown, the SNAC router is expected to treat the infrastructure interface as an advertising interface as described in Section 6.2.2 of [RFC4861]. There are two sets of information that need to be sent in an RA; if neither is present, then the SNAC router SHOULD NOT send an RA even if it is treating the infrastructure interface as an advertising interface.

These two sets of information are the on-link prefix, if any, that is to be advertised. Whether or not such a prefix is advertised, and what exactly is advertised regarding that prefix, is determined by the state machine. The other set of information is a set of routes to prefixes on the stub network. Whenever the SNAC router knows of a reachable (scope is not link-local) prefix on the stub network, it includes an RIO option in the RA on the infrastructure network indicating that that prefix is reachable through the SNAC router.

It is important to note that it is possible for an on-link, routable prefix to be advertised and then withdrawn on the stub network, but for it to still be valid, and for there to still be some communication occurring using that prefix. In order to avoid prematurely interrupting such communication, the SNAC router MUST maintain a list of prefixes known to be valid on the stub network, even if those prefixes have been deprecated, and MUST include RIO options for all such prefixes in the RAs that it sends on the adjacent infrastructure link.

5.1.2.1. Status of IP addressability on adjacent infrastructure link unknown (STATE-UNKNOWN)

When the SNAC router interface first connects to the AIL, it MUST begin router discovery.

If, after router discovery has completed, no suitable on-link prefix has been found, the router moves this interface to STATE-BEGIN-ADVERTISING (Section 5.1.2.3).

If, during router discovery, a suitable on-link prefix is found, the router moves the interface to STATE-SUITABLE (Section 5.1.2.2).

In this state, the SNAC router MUST NOT treat this interface as an advertising interface as described in Section 6.2.2 of [RFC4861].

5.1.2.2. IP addressability already present on adjacent infrastructure link (STATE-SUITABLE)

When a new host appears on the AIL and sends an initial Router Solicitation message, if it does not receive a suitable on-link prefix, it will not be able to communicate. Consequently, the SNAC router MUST monitor Router Solicitation and Router Advertisement messages on the interface in order to determine whether a prefix that has been advertised on the link is still being advertised. To accomplish this, the SNAC router uses two complementary methods: router staleness detection and neighbor unreachability detection.

5.1.2.2.1. Router staleness detection

The SNAC router MUST listen for Router Advertisement messages on the AIL to which the interface is attached, and record the time at which each Router Advertisement was received. The router MUST NOT consider any Router Advertisement that is older than STALE_RA_TIME to be suitable. When the last non-stale Router Advertisement message containing a suitable prefix on the link is marked stale, the SNAC router MUST move the interface to STATE-BEGIN-ADVERTISING.

5.1.2.2.2. Router Unreachability Detection

For each suitable prefix, the SNAC router MUST monitor the state of reachability to the router(s) that advertised it as described in ([RFC4861], Section 7.3.1) using a ReachableTime value of no more than MAX_SUITABLE_REACHABLE_TIME. The reason for this is that if no router providing the on-link prefix on the AIL is reachable, then when a new host joins the network, it will have no suitable on-link prefix to use for autoconfiguration, and thus will be unable to communicate with hosts on the stub network.

Whenever the `ReachableTime` for a router advertising a suitable prefix exceeds `MAX_SUITABLE_REACHABLE_TIME`, the SNAC router MUST send unicast Neighbor Solicitation messages as described in Section 7.2.2 of [RFC4861] until either a response is received, which resets `ReachableTime` to zero, or the maximum number of retransmissions has been sent.

The SNAC router MUST listen for Router Solicitation messages on the AIL. When a Router Solicitation message is received, if none of the on-link routers on the AIL are marked reachable, the SNAC router MUST move this interface to the `STATE-BEGIN-ADVERTISING` state (Section 5.1.2.3).

If the scheduled time for sending a periodic unsolicited multicast RA message arrives, and there are no routers advertising suitable prefixes that have a `ReachableTime` that is less than `MAX_SUITABLE_REACHABLE_TIME`, then the router MUST move this interface to the `STATE-BEGIN-ADVERTISING` state.

5.1.2.3. IP addressability not present on adjacent infrastructure link (`STATE-BEGIN-ADVERTISING`)

In this state, the SNAC router generates its own on-link prefix for the interface. This prefix has a valid and preferred lifetime of `STUB_PROVIDED_PREFIX_LIFETIME` seconds. The SNAC router sends a Router Advertisement (RA) message containing this prefix in a Prefix Information Option (PIO). In the PIO, the 'A' flag bit (autonomous configuration) Section 4.6.2 of [RFC4861] MUST be set and the 'L' flag bit (on-link prefix) MUST also be set. Link-layer technologies that require the 'L' flag bit to be cleared are out of scope of this document.

The 'SNAC Router' flag bit ([I-D.ietf-6man-snac-router-ra-flag]) MUST be set in the RA flags field. The values of the 'M' and 'O' flag bits MUST be copied from the respective 'M' and 'O' flag bit values seen in the most recent (unicast or multicast) RA received from a non-SNAC-router. For the selection of the most recent RA, the following RAs MUST be excluded:

- * An RA received from a router longer ago than the Router Lifetime period indicated in the RA header. This only applies for a non-zero Router Lifetime value.

If there is no RA received from a non-SNAC-router, both 'M' and 'O' flag bits MUST be cleared.

The sent Router Advertisement message MUST also include a Route Information option (Section 2.3 of [RFC4191]) for each routable prefix advertised on the stub network.

After having sent the initial Router Advertisement, the SNAC router moves the interface into the STATE-ADVERTISING-SUITABLE state (Section 5.1.2.4).

5.1.2.4. IP addressability not present on adjacent infrastructure link (STATE-ADVERTISING-SUITABLE)

When entering this state, if the router MUST begin treating the interface as an advertising interface as described in Section 6.2.2 of [RFC4861] if it is not already doing so.

The SNAC router sends a periodic unsolicited multicast Router Advertisement message, as described in Section 5.1.2.3, at a random time between MinRtrAdvInterval and MaxRtrAdvInterval.

The SNAC router may receive a Router Advertisement message containing one or more suitable on-link prefixes on the AIL. If any of these prefixes are different from the prefix the SNAC router is advertising as the on-link suitable prefix, and the 'SNAC Router' flag bit is not set in the Router Advertisement flags field, the SNAC router moves the interface to STATE-DEPRECATING (Section 5.1.2.5).

If the 'SNAC Router' flag bit is set in the RA header flags field, then one of the following must be true in order for that prefix to be considered suitable:

- * The prefixes are equal. In this case, the interface remains in STATE-ADVERTISING-SUITABLE.
- * The prefix the SNAC router is advertising is a ULA prefix [RFC4193], and the received prefix is a non-ULA prefix. In this case, the interface moves into the STATE-DEPRECATING (Section 5.1.2.5) state.
- * Both prefixes are ULA prefixes, and the received prefix, considered as a 128-bit big-endian unsigned integer, is numerically lower, then the interface moves to STATE-DEPRECATING (Section 5.1.2.5).
- * Otherwise the interface remains in STATE-ADVERTISING-SUITABLE.

5.1.2.5. SNAC router deprecating the on-link prefix it is advertising (STATE-DEPRECATING)

On entry to this state, the SNAC router has been treating the interface as an advertising interface as described in Section 6.2.2 of [RFC4861], and MUST continue to do so.

When the SNAC router has detected the availability of suitable on-link prefix on the AIL to which the interface is attached, and that prefix is preferable to the one it is advertising, it continues to advertise its own prefix, but deprecates it:

- * the preferred lifetime for its prefix should be set to zero in subsequent Router Advertisement messages.
- * the valid lifetime for its prefix should be reduced with each subsequent Router Advertisement messages.
- * the usability of the infrastructure-provided on-link prefix should be monitored as in the STATE-SUITABLE state; if during the deprecation period, the SNAC router detects that there are no longer any suitable prefixes on the link, as described in Section 5.1.2.2.1 or in Section 5.1.2.2.2, it MUST return the interface to the STATE-BEGIN-ADVERTISING (Section 5.1.2.3) state and resume advertising its prefix with the valid and preferred lifetimes described there.

In this state, the valid lifetime (VALID) is computed based on three values: the current time when a router advertisement is being generated (NOW), the time at which the new suitable on-link prefix advertisement was received (DEPRECATE_TIME), and STUB_PROVIDED_PREFIX_LIFETIME. All of these values are in seconds. VALID is computed as follows:

$$\text{VALID} = \text{STUB_PROVIDED_PREFIX_LIFETIME} - (\text{NOW} - \text{DEPRECATE_TIME})$$

If VALID is less than MaxRtrAdvInterval seconds, the SNAC router does not include the deprecated prefix in the router advertisement. Note that VALID could be less than zero. Otherwise, the prefix is provided in the advertisement, but with a valid lifetime of VALID.

5.2. Managing addressability on the stub network

How addressability is managed on stub networks depends on the nature of the stub network. For some stub networks, the SNAC router can be sure that it is the only router. For example, a SNAC router that is providing a Wi-Fi network for tethering will advertise its own SSID and use its own joining credentials; in this case, it can assume that it is the only router for that network, and advertise a default route and on-link prefix just like any other router.

However, some stub networks are more cooperative in nature, for example IP mesh networks. On such networks, multiple SNAC routers may be present and be providing addressability and reachability.

In either case, some SNAC router connected to the stub network **MUST** provide a suitable on-link prefix (the OSNR prefix) for the stub network. If the stub network is a multicast-capable medium where Router Advertisement messages are used for router discovery, the same mechanism described in Section 5.1.2 is used.

Stub networks that do not support the use of Router Advertisements for router discovery must use some similar mechanism that is compatible with that type of network. Describing the process of establishing a common OSNR prefix on such networks is out of scope for this document. Some informative discussion on this topic is in Appendix D.

5.2.1. Maintenance across SNAC router restarts

SNAC routers may restart from time to time; when a restart occurs, the SNAC router may have been advertising state to the network which, following the restart, is no longer required.

For example, suppose there are two SNAC routers connected to the same infrastructure link. When the first SNAC router is restarted, the second takes over providing an on-link prefix. Now the first router rejoins the link. It sees that the second SNAC router's prefix is advertised on the infrastructure link, and therefore does not advertise its own.

This behavior can cause problems because the first SNAC router no longer sees the on-link prefix it had been advertising on infrastructure as on-link. Consequently, if it receives a packet to forward to such an address, it will forward that packet directly to a default router, if one is present; otherwise, it will have no route to the destination, and will drop the packet.

To address this problem, SNAC routers SHOULD remember the last time a prefix was advertised across restarts. On restart, the router configures the prefix on its interface but does not advertise it in Router Advertisements. Devices that are still using that prefix will be seen as on-link to the router, and so packets will be delivered using ND on-link rather than forwarded to the default router.

When a SNAC router has only flash memory with limited write lifetime, it may be inappropriate to do a write to flash every time a multicast RA message containing a prefix is sent. In this case, the router SHOULD record the set of prefixes that have been advertised on infrastructure and the maximum valid lifetime that was advertised. On restart, the router should assume that hosts on the infrastructure link have received advertisements for any such prefixes.

When possible, it is best if all SNAC routers serving a particular stub network use the same 64-bit prefix on the AIL. For example, Thread SNAC routers use bits from the Thread Extended PAN ID to generate the ULA prefix's Global ID and Subnet ID. The Global ID generation conforms to [RFC4193] because the Extended PAN ID is generated randomly using the same mechanism that is specified in RFC 4193 for the ULA prefix bits.

5.2.2. Generating a per-SNAC-router ULA Site Prefix

In order to be able to provide addressability either on the stub network or on an adjacent infrastructure network, a SNAC router MUST allocate its own ULA site prefix. ULA prefixes, described in Unique Local IPv6 Unicast Addresses ([RFC4193]) are randomly allocated prefixes. A SNAC router MUST allocate a single ULA site prefix for use in providing on-link prefixes to the stub network and the adjacent infrastructure link as described in Section 5.1.2.3.

Any ULA link prefixes allocated by a SNAC router SHOULD be maintained across reboots, and SHOULD remain stable over time. (TBD: mention the SHOULD exception cases) However, for privacy reasons, a SNAC router that roams from network to network SHOULD allocate a different ULA link prefix each time it connects to a different infrastructure network, unless configured to behave otherwise.

5.2.3. Using DHCPv6 Prefix Delegation to acquire a prefix to provide addressability

If DHCPv6 prefix delegation and IPv6 service are both available on the infrastructure link, then the SNAC router MUST attempt to acquire a prefix using DHCPv6 prefix delegation. Using a prefix provided by the infrastructure DHCPv6 prefix delegation service means (assuming the infrastructure is configured correctly) that routing is possible between the stub network links and all links on the infrastructure network, and possibly to the general internet.

By contrast, if the prefix generated by the SNAC router is used, reachability is only possible between the stub network and the AIL. The OSNR prefix in this case is not known to the infrastructure network routing fabric, so even though packets might be able to be forwarded to the intended destination, there would be no return path. So when the only prefix that is available is the one provided by the SNAC router, cloud services will not be reachable via IPv6, and infrastructure-provided NAT64 will not work. Therefore, when the SNAC router is able to successfully acquire a prefix using DHCPv6 PD, it MUST use DHCPv6 PD rather than the ULA Link prefix it allocated for the stub network out of its ULA site prefix.

A SNAC router MUST request stub network prefixes with length 64. It does so by sending an IA_PD option for each prefix, each with a different IAID, containing an IA_PREFIX with a hint of 64 as described in Section 18.3.9. of [RFC8415]. If the SNAC router obtains a prefix with length less than 64, it SHOULD generate a /64 from the obtained prefix by padding with zeros. If the SNAC router obtains a prefix with length greater than 64, the SNAC router MUST treat the prefix as unsuitable and allocate a ULA link prefix out of its ULA site prefix instead.

When multiple prefixes are available for delegation (e.g., both Global Unicast Address (GUA) and Unique Local Address (ULA) prefixes), a SNAC router MUST select prefixes based on the following criteria, evaluated in order:

- * Single OSNR prefix constraint: For constrained stub networks (e.g., 6LoWPAN, Thread mesh networks) that have limited support for multiple OSNR prefixes, a SNAC router MUST select only the single best prefix. Prefix type GUA is MUST be preferred over ULA, then the prefix with the longest preferred and valid lifetimes is chosen for distribution.

- * Multiple OSNR prefix constraint: For stub networks without a single OSNR prefix constraint, the GUA and ULA prefixes with the longest preferred and valid lifetimes are chosen for distribution. Distributing both GUA and ULA prefixes allows hosts to decide how they will communicate.

The timeout/lifetime-based selection ensures that the stub network avoids frequent renumbering events that can disrupt ongoing communications and create excessive maintenance overhead. SNAC routers SHOULD monitor delegated prefix lifetimes and re-evaluate prefix selection when lifetimes are renewed or when new prefixes become available.

A SNAC router MUST check in the server's Advertise message that the preferred lifetime a DHCPv6-PD server can offer is at least MIN_PD_PREFIX_LIFETIME prior to requesting a prefix delegation to that server. If no DHCPv6-PD server can offer this, the SNAC router MUST treat all potential DHCPv6-PD prefixes as unsuitable and allocate a ULA link prefix out of its ULA site prefix instead.

5.2.3.1. Lifetime of IPv6 prefixes acquired using DHCPv6 Prefix Delegation

It is possible that a SNAC router might obtain a prefix from a DHCPv6 server using prefix delegation and then something about the infrastructure network attachment might change that affects the validity of that prefix for use on the stub network. The section of [I-D.ietf-dhc-rfc8415bis] titled "Refreshing Configuration Information" discusses the various scenarios that can occur. The DHCPv6 prefix delegation client being used by the SNAC router is assumed to conform to this specification.

Situations that can occur include (but are not limited to):

- * DHCPv6 server becomes unavailable
- * SNAC router is moved to a different link
- * A renumbering event results in the old prefix being replaced with a new one

The SNAC router MUST NOT use a prefix once the DHCPv6-PD client has determined that it is no longer valid. If the DHCPv6-PD client provides a new prefix, and the old prefix is still valid, the SNAC router SHOULD explicitly deprecate the old prefix at the same time that it first advertises the new prefix.

If the DHCPv6-PD client determines that the prefix it provided to use as the OSNR prefix is no longer valid, and no replacement prefix is provided by the DHCPv6 server, then the SNAC router MUST switch to the ULA link prefix that it has allocated for use on the stub network. In the case that the DHCPv6-PD client is unable to renew its lease on the current OSNR prefix, and time between the T2 interval for the prefix assignment Section 21.4 of [I-D.ietf-dhc-rfc8415bis] and the end of the lease has been reached, then the SNAC router MUST deprecate the DHCPv6-PD-provided OSNR prefix and begin advertising the ULA link prefix.

A failure to renew the DHCPv6-PD-provided OSNR prefix could be because the SNAC router has been disconnected from one AIL and moved to a different AIL. In this situation, if the new AIL also has IPv6 service and DHCPv6-PD service, the DHCPv6 client will get a clear indication that the old prefix is no longer valid. However, it may be that no DHCPv6-PD service is available on the new link, either because it is an IPv4-only link or because it's an IPv6-capable link that doesn't provide DHCPv6 service. In this situation, if the SNAC router remains connected to the link and no DHCPv6 service appears, the DHCPv6-PD-provided OSNR prefix will eventually time out and be replaced. The SNAC router SHOULD NOT attempt to replace it prior to this normal timeout process, because there is no benefit to changing the OSNR prefix on the stub network in such a situation, and it's possible that the SNAC router will return to the other link before the OSNR prefix expires.

5.3. Managing reachability on the adjacent infrastructure link

SNAC routers MUST advertise reachability to stub network OSNR prefixes on any AIL to which they are connected. If the SNAC router is advertising a suitable prefix on any interface, any such prefixes MUST be advertised on that interface in the same Router Advertisement message that is advertising the suitable prefix, to avoid unnecessary multicast traffic.

Each stub network will have some set of prefixes that are advertised as on-link for that network. A SNAC router connected to that stub network SHOULD advertise reachability to all such prefixes on any AIL to which it is attached using router advertisements.

A SNAC router MUST NOT advertise itself as a default router on an AIL by setting a non-zero Router Lifetime value in the header of its Router Advertisements.

5.4. Managing reachability on the stub network

The SNAC router MAY advertise itself as a default router on the stub network, if it itself has a default route on the AIL. In some cases it may not be desirable to advertise reachability to the Internet as a whole; in this case the SNAC router is not required to advertise itself as a default router.

If the SNAC router is not advertising itself as a default router on the stub network, it MUST advertise reachability to any prefixes that are being advertised as on-link on AILs to which it is attached. This is true for prefixes it is advertising, and for other prefixes being advertised on that link.

Note that in some stub network configurations, it is possible for more than one SNAC router to be connected to the stub network, and each SNAC router may be connected to a different AIL. In this case, a SNAC router advertising a default route may receive a packet destined for a link that is not an AIL for that router, but is an AIL for a different router. In such a case, if the infrastructure is not capable of routing between these two AILs, a packet which could have been delivered by another SNAC router will be lost by the SNAC router that received it.

Consequently, SNAC routers SHOULD be configurable to not advertise themselves as default routers on the stub network. SNAC routers SHOULD be configurable to explicitly advertise AIL prefixes on the stub network even if they are advertising as a default router. The mechanisms by which such configuration can be accomplished are out of scope for this document.

It is also possible that SNAC routers for more than one stub network may be connected to the same AIL. In this case, the SNAC routers will be advertising Route Information Options (RIO) in their Router Advertisement messages for their OSNR prefixes. SNAC routers MUST track the presence of such routes, and MUST advertise reachability to them on interfaces connected to stub networks.

5.5. Providing discoverability between stub network links and infrastructure network links

Since DNS-SD is in wide use, and provides for ad-hoc, self-configuring advertising using the mDNS transport, this is a suitable mandatory-to-implement protocol for stub networks, which must be able to attach to infrastructure networks without the help of new mechanisms provided by the infrastructure. Therefore, SNAC routers MUST provide DNS-SD service as described in this section.

5.5.1. Discoverability by hosts on adjacent infrastructure links

The adjacent infrastructure can be assumed to already enable some service discovery mechanism between hosts on the infrastructure network, and can be assumed to provide a local DNS resolver. Therefore, this document does not define a stub-network-specific mechanism for providing these services on the infrastructure network.

In some cases it will be necessary for hosts on the AIL to be able to discover devices on the stub network. In other cases, this will be unnecessary or even undesirable. For example, it may be undesirable for devices on an AIL to be able to discover devices on a Wi-Fi tether provided by a mobile phone.

One example of a use case for stub networks where such discovery is desirable is the constrained network use case. In this case a low-power, low-cost stub network provides connectivity for devices that provide services to the infrastructure. For such networks, it is necessary that devices on the infrastructure be able to discover devices on the stub network.

The most basic use case for this is to provide feature parity with existing solutions like multicast DNS (mDNS). For example, a light bulb with built-in Wi-Fi connectivity might be discoverable on the infrastructure link to which it is connected, using mDNS, but likely is not discoverable on other links. To provide equivalent functionality for an equivalent device on a constrained network that is a stub network, the stub network device must be discoverable on the infrastructure link (which is an AIL from the perspective of the stub network).

If services are to be advertised using DNS Service Discovery [RFC6763], there are in principle two ways to accomplish this. One is to present services on the stub network as a DNS zone which can then be configured as a browsing domain in the DNS ([RFC6763], Section 11). The second is to advertise stub network services on the AIL using multicast DNS (mDNS) [RFC6762].

Because this document defines behavior for SNAC routers connecting to infrastructure networks that do not provide any new mechanism for integrating stub networks, there is no way for a SNAC router to provide DNS-SD service on an infrastructure link in the form of a DNS zone in which to do discovery. Therefore, service on the infrastructure link MUST be provided using an Advertising Proxy, as defined in [I-D.ietf-dnssd-advertising-proxy].

One limitation of this solution is that it requires that hosts on the stub network use the DNS-SD Service Registration Protocol [I-D.ietf-dnssd-srp] to register their DNS-SD advertisements. This means that in the case of a stub network used for WiFi tethering, hosts on the stub network will not be discoverable by hosts on the infrastructure network. Any solution to this problem would require that the SNAC router provide a Discovery Proxy [RFC8766]. However, a discovery proxy is queried using DNS, not mDNS. This requires assistance from the infrastructure network, and is therefore out of scope for this document.

5.5.2. Providing discoverability of adjacent infrastructure hosts on the stub network

Hosts on the stub network may need to discover hosts on the AIL, or on the stub network. In an IoT use case, for example, there might be a light switch on the stub network which needs to be able to actuate a light bulb connected to the AIL. In order to know where to send the actuation messages, the light switch will need to be able to discover the light bulb's address somehow.

Because the stub network is managed by SNAC routers, any DNS resolver that's available on the stub network will necessarily be provided by one or more SNAC routers. This means that the SNAC router can enable discovery of hosts on the infrastructure network by hosts on the stub network using a Discovery Proxy [RFC8766]. The Discovery Proxy can be advertised as available to hosts on the stub network through the DNS resolver provided on the stub network, as described in Section 11 of [RFC6763].

By implication, this means that SNAC routers MUST provide a DNS resolver. In addition, SNAC routers MUST provide DNS zones for each AIL, and MUST list these zones in the list of default browsing zones as defined in RFC6763. [[WG TBD: we need to say how these zones are named. Or refer to the Advertising Proxy doc and have that doc say how they are named.]]

The SNAC router MUST also maintain an SRP registrar and use registrations made through that registrar to populate a DNS zone which is advertised as a default browsing domain, as above. This SRP registrar MUST be advertised on the stub network either using the dnssd-srp and/or dnssd-srp-tls service names or some stub-network-specific mechanism, the details of which are out of scope for this document.

6. Providing reachability to IPv4-only services to hosts on the stub network

stub networks rely on IPv6 to enable routing between links, which would not be possible with IPv4 due to the limited availability and functionality of IPv4 router discovery mechanisms (such as ICMP Router Discovery Messages [RFC1256]) compared to IPv6 Router Advertisements. However, it can still be useful for hosts on the stub network to establish communications with IPv4-only hosts on the infrastructure network.

Although NAT64 provides IPv6-only hosts with a way to reach IPv4 hosts, there is no easy way for an IPv4 host to use NAT64 to originate communication with an IPv6 host. Therefore, this document enables IPv6 hosts on the stub network to discover and reach with IPv4 hosts on infrastructure, but does not provide a way for IPv4-only hosts on infrastructure to communicate to IPv6 hosts on the stub network.

This should be acceptable because hosts on the infrastructure network should not be IPv4-only, since the SNAC router is providing IPv6 service on the infrastructure network that is suitable for communicating using IPv6 to hosts on the SNAC network--there should not be any hosts on the infrastructure network that can't communicate with hosts on the stub network unless such hosts do not have an IPv6 stack at all.

So the purpose of providing IPv4 connectivity for SNAC hosts is to enable communication with arbitrary IPv4 hosts which may not be on the AIL. This is accomplished by providing NAT64 address translation in the SNAC router, and by enabling service discovery using a Discovery Proxy.

Stub Network routers must be capable of providing NAT64 themselves, and must be capable of discovering the availability of NAT64 service on the infrastructure network and providing it when it is available and suitable.

Some network media may provide their own mechanisms for advertising NAT64 service to the stub network. If such a mechanism is available, SNAC routers MUST use the mechanism provided by the network medium used on the stub network to advertise NAT64 service. Otherwise, NAT64 service MUST be advertised using the PREF64 Router Advertisement option [RFC8781].

There are four possible combinations of circumstances in which to consider how to provide NAT64 service:

1. Infrastructure provides DHCPv6 PD support, and the infrastructure network provides NAT64
2. Infrastructure provides no DHCPv6 PD support, Infrastructure is providing NAT64, and there is no IPv4 on infrastructure
3. Infrastructure provides no DHCPv6 PD support, Infrastructure is providing NAT64, and there is IPv4 on infrastructure
4. Infrastructure provides no DHCPv6 PD support, infrastructure is not providing NAT64 (and may also not be providing IPv6), and there is IPv4 on infrastructure

In the first case, infrastructure-provided NAT64 is preferred, and the SNAC router MUST advertise this service to the stub network.

In the second case, there is no way to provide connectivity to the infrastructure: there is no IPv6 routing other than to the adjacent infrastructure link, because there is no routable prefix, and there is no NAT64 for the same reason, and there is no IPv4, so the SNAC router can't do NAT64 on its own. In this case, the SNAC router MUST NOT advertise NAT64 service.

In the third case, despite the infrastructure providing NAT64, nodes in the stub network can't use it, so the SNAC router MUST provide its own NAT64 service.

In the fourth case, the SNAC router MUST provide its own NAT64 service.

An additional complication is that there may be more than one SNAC router connecting the stub network to infrastructure. In this case, it may be desirable to limit the number of SNAC routers providing NAT64 service, or it may be acceptable for all SNAC routers to provide it.

In the latter case, this should not be a problem: since each SNAC router is using its own ULA site prefix to provide NAT64, any 5-tuple that goes through a SNAC router's NAT64 translator will necessarily have as its destination an IPv6 address in a particular NAT64 prefix, and that address will select the correct SNAC router through which to send the packet for translation. This also works on the return path because each SNAC router has its own IPv4 address, and the return packet will be destined for that IPv4 packet, and hence will always return through the SNAC router that translated it on the way out.

A further complication is that in some cases, some SNAC routers connected to the stub network may not be able to advertise an infrastructure-provided NAT64 prefix, while others may. In this case, when the infrastructure-provided NAT64 service appears on the stub network, SNAC routers that are not able to advertise an infrastructure NAT64 service MUST NOT do so.

To differentiate between infrastructure-provided NAT64 service and SNAC router-provided NAT64 service, SNAC routers that advertise infrastructure-provided NAT64 service MUST use a preference of medium for this service. SNAC routers advertising their own service MUST use a preference of low.

In some cases a SNAC router may be administratively configured with a NAT64 prefix. In this situation, the SNAC router MUST advertise the prefix with a preference of high.

SNAC routers must monitor the advertisement of other NAT64 prefixes on the stub network. If a SNAC router is advertising a NAT64 prefix, and a NAT64 prefix is advertised on the stub network with a higher preference, the SNAC router SHOULD deprecate the prefix it is advertising.

6.1. NAT64 provided by infrastructure

Stub networks are defined to be IPv6-only because it would be difficult to implement a stub network using IPv4 technology. However, stub network devices may need to be able to communicate with IPv4-only services either on the infrastructure network, or on the global internet. Ideally, the infrastructure network fully supports IPv6, and all services on the infrastructure network are IPv6-capable. In this case, perhaps the infrastructure network provides NAT64 service to IPv4-only hosts on the internet. In this ideal setting, the SNAC router need do nothing—the infrastructure network is doing it all.

In this situation, if there are multiple SNAC routers, each connected to the same AIL, there is no need for special behavior—each SNAC router can advertise a default route, and any SNAC router may be used to route NAT64 traffic. If some SNAC routers are connected to different AILs than others, some of which support NAT64 and some of which do not, then the default route may not carry traffic to the correct link for NAT64 service. In this case, a more specific address to the infrastructure NAT64 prefix(es) MUST be advertised by those SNAC routers that are able to discover it.

In order for infrastructure-provided NAT64 to work, the stub network must have an OSNR prefix that is known to the infrastructure. Typically this means that the SNAC router must have acquired this prefix using DHCPv6 prefix delegation. Unless otherwise configured to do so, the SNAC router **MUST NOT** advertise infrastructure-provided NAT64 service on the stub network if it has not acquired the OSNR prefix through DHCPv6 prefix delegation.

6.2. NAT64 provided by SNAC router(s)

Most infrastructure networks at present do not provide NAT64 service. Many infrastructure networks do not provide DHCPv6 prefix delegation. In these cases it is necessary for SNAC routers to be able to provide NAT64 service if IPv4 hosts are to be reachable from the stub network. Therefore, SNAC routers **MUST** be capable of providing NAT64 service to the stub network. When infrastructure-provided NAT64 service is not present or is not usable, and when no other NAT64 service is already advertised on the stub network, SNAC routers **MUST**, by default, enable their own NAT64 service and advertise it on the stub network.

To provide NAT64 service, a SNAC router must allocate a NAT64 prefix. For convenience, the stub network allocates a single prefix out of the ULA site prefix that it maintains. Out of the 2^{16} possible subnets of the /48, the SNAC router **SHOULD** use the numerically highest /64 prefix.

If there are multiple SNAC routers providing connectivity between the stub network and infrastructure, each stub network uses its own NAT64 prefix—there is no common NAT64 prefix. The reason for this is that NAT64 translation is not stateless, and is tied to the SNAC router's IPv4 address. Therefore, each NAT64 egress is not equivalent.

A stub network that services a Wi-Fi stub network **SHOULD** provide DNS64 translation: hosts on the stub network cannot be assumed to be able to do DNS64 synthesis in the stub resolver. In this case the DNS resolver on the SNAC router **MUST** honor the 'CD' and 'DO' flag bits if received in a request, since this indicates that the stub resolver on the requestor intends to do DNSSEC validation. In this case, the resolver on the SNAC router **MUST NOT** perform DNS64 synthesis.

On specific stub networks it may be desirable to require the stub network device to perform DNS64 synthesis. Stub network routers for such networks do not need to provide DNS64 synthesis. Instead, they MUST provide an `ipv4only.arpa` answer that advertises the NAT64 prefix for that SNAC router, and MUST provide an explicit route to that NAT64 prefix on the stub network using RA or whatever technology is specific to that stub network type.

In constrained networks it can be very useful if stub network resolvers provide the information required to do DNS64 translation in the answer to the AAAA query. If the answer to an AAAA query comes back with "no data" (not NXDOMAIN), this suggests that there may be an A record. In this case, the stub network's resolver SHOULD attempt to look up an A record on the same name. If such a record exists, the resolver SHOULD return no data in the Answer section of the DNS response, and SHOULD provide any CNAME records that were involved in returning the "no data" answer to the AAAA query, and SHOULD provide any A records that were ultimately returned, in the Additional section. The resolver should also include an `ipv4only.arpa` record in the Additional section.

7. Services Provided by SNAC routers

In order to provide network access, SNAC routers must provide some network services to the stub network. In this document the following services have been discussed:

DNS Resolver: The stub network MUST provide a DNS resolver. If RAs are in use on the stub network, the DNS resolver is advertised in the Router Advertisement Recursive DNS Server (RDNSS) option. If RAs are not in use on the stub network, then the mechanism whereby the DNS resolver is advertised by the SNAC router is specific to that type of stub network.

DHCPv6 Server: The use of DHCPv6 on the stub network is NOT RECOMMENDED. In some cases it may be necessary, but should be disabled by default if the SNAC router provides this capability at all.

Discovery Proxy: In order to discover services on the AIL, SNAC routers MUST act as Discovery Proxies for any AILs to which they are attached.

SRP Registrar: SNAC routers MUST provide SRP registrar service. This service MUST be advertised using DNS-SD in a legacy browsing domain that is discoverable through the SNAC router's resolver.

Legacy Browsing Domains: The stub resolver must advertise legacy

browsing domains for each AIL, for the zone that is maintained by its SRP service, and in addition must list the legacy browsing domains provided by the infrastructure network, if any.

NAT64: As mentioned above, SNAC routers may need to provide NAT64 service so that devices on the stub network can communicate with IPv4 hosts on the infrastructure network and the global internet.

8. IANA Considerations

This document has no IANA actions.

9. Security Considerations

Because a SNAC router operates as an IPv6 router that sends and receives IPv6 Neighbor Discovery protocol messages, the security considerations of Section 11 of [RFC4861] apply. No additional security considerations are identified.

10. Normative References

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Appendix A. Analysis of deployment scenarios in which a SNAC router could cause problems

A.1. Unmanaged home network

In this scenario, a non-expert home user connects a SNAC router to their own unmanaged home network. This is the key intended use case for stub networks. This document describes how to implement a SNAC router such that it operates correctly in this situation, whether the ISP is providing IPv6 reachability to the Internet or not.

In some unmanaged network settings, there is a "guest" network in addition to the main network. In this configuration, if a SNAC router is added to the guest infrastructure network, no communication will be possible. The general intended behavior of the guest network is to isolate untrusted hosts. Since this would be the intended behavior on the part of the owner of the network, it won't be a surprise to them, since they had to explicitly give the SNAC router's owner the guest network credentials and not the main network credentials. This should also mean that the owner of the SNAC router will not expect it to function in this scenario.

An additional feature of some unmanaged networks is that the owner of the network can choose to isolate all devices on the network, so that devices on the network are able to use the Internet, but not communicate with each other. This is essentially the same as being connected to the guest network, except that there is no other network. In this case, one can assume that the owner of the network doesn't expect any devices attached to the network to be able to communicate with any other device, so the failure of devices connected to infrastructure to communicate with devices on the stub network would not be a surprise. The owner of the SNAC router might be surprised in this case, but ultimately the owner of the infrastructure network gets to make this decision, and there isn't anything a SNAC router can or should do on behalf of the SNAC router's owner in this case.

A.2. Use on an unmanaged (non-home) IPv6 network

In this scenario there is a site that is not a home, so perhaps a restaurant or business, where there is no network operator per se, and the network is deployed similarly to a home network. There is little difference between this scenario and an unmanaged home network, but expectations may be different. In particular, it is very common in such settings for there to be a guest network for visitors, or for the network to enforce isolation between all nodes connected to it.

A.3. Use on a managed network

In this scenario, a non-expert user attaches a SNAC router to an infrastructure network that's managed. This network has correctly deployed RA Guard and/or port-based access control. As a result, the SNAC router won't succeed in advertising a prefix on the managed network. Communications originating on the stub network that are able to communicate using NAT64 will still work.

In the managed network case, it's possible that the network operator is willing to permit SNAC routers to be attached to the network by users. In this case, they might either not deploy RA guard, or they might deploy working DHCPv6 prefix delegation. This could be PD-per-host (where hosts are encouraged to use prefix delegation) or just ordinary prefix delegation (where hosts are given prefix delegation if they ask for it, but not encouraged to ask for it).

In such a situation, if DHCPv6 PD works on the infrastructure link, the SNAC router will function correctly, because the delegated prefix will be correctly routed.

It's worth noting that IPv4 devices that act similarly to SNAC routers, using NAT64, already exist and may indeed use the stub network functionality to support internal connections that aren't even apparent to the user. In this case the SNAC router is not relying on RA to function because it's using its IPv4 address and NAT64 to provide connectivity, so there is no management issue even if RA is blocked. This is a reasonable use case for IPv6, and the current stub network document does in fact enable this use case.

When a SNAC router is attached to an infrastructure network that has deployed RA guard and does not support DHCPv6 prefix delegation, and where that infrastructure network does allow the use of multicast DNS, services advertised on the stub network will be discoverable on the infrastructure network, but will not be reachable.

A.3.1. Managed networks where DHCPv6 is required but RA guard is not present

There can be a case where an infrastructure does not implement RA guard, does not advertise what this document considers to be an "acceptable" prefix, and does provide addressing using DHCPv6 IA_NA. In this situation, it could be the case that two ULA prefixes are being advertised as on-link and one is being advertised as permitting autonomous configuration.

In the case a host that is attempting to communicate with a device using a site ULA prefix on a different link may choose a ULA address as a source address. If it were to choose the autonomously-configured ULA address as its source address, this would fail, because there is no route back to the SNAC-router-provided ULA prefix.

However, this can only happen in practice if the host did not receive an address from DHCPv6. In this case, the host would not be able to communicate anyway. The problem that might occur here is that a series of IP packets with an unexpected source address are sent to a device on another link, and the device would be unable to send a response.

In such scenarios there is no way to actually know based on the network configuration what the operator's intention was. An operator that sees a problem with this can react by implementing RA guard or by blocking unknown source addresses at the router, and in so doing they would be expressing their intention. This configuration would not cause any new problem: a host that could communicate would still be able to communicate, and a host that could not communicate would not become able to communicate.

The one scenario where a communication problem can actually be expected is when there is a GUA prefix advertised by infrastructure but no ULA prefix, but there is a ULA destination to reach. In this case, the longest-matching-prefix algorithm could choose the SNAC-router-provided ULA prefix as a source address to reach the site-provided ULA destination, and in this case communication would fail. Only happy eyeballs can correct this situation.

A.3.2. Use on a managed network without IPv6

In this scenario, there is no IPv6 service being intentionally advertised on a managed network. Operators of such networks may not be aware of the possibility of configuring RA guard. In this situation, a SNAC router will connect and advertise services, which will be reachable just as they would be in a similar unmanaged network. A SNAC router that conforms to this specification will not advertise an IPv6 default route. Therefore, it should not cause operational problems, just as connecting an IPv4 NAT gateway in the same scenario would not cause operational problems.

Appendix B. Router Advertisements on the Infrastructure Network

An active SNAC router sends periodic unsolicited multicast Router Advertisements as well as unicast Router Advertisements on the infrastructure network. These Router Advertisements are filled with the following values consistent with the message format given in Section 4.2 of [RFC4861]:

- * Router Lifetime: A SNAC router never advertises itself as a default router on infrastructure. Therefore, the router lifetime is always zero in a SNAC router's Router Advertisements sent on the AIL.
- * For the 'M' and 'O' flag bits, section Section 5.1.2.3 specifies that they must be zero.
- * The 'SNAC router' flag bit xref target="I-D.ietf-6man-snac-router-bit" TBD WaitRef MUST be 1.
- * In the Cur Hop Limit field: 0
- * In the Reachable Time field: 0
- * In the Retrans Timer field: 0
- * In the options, with the exception of the options listed below, SNAC routers MUST NOT send any RA options, since these other options are for managing the network, and the SNAC router is not responsible for managing the infrastructure network.
 - Source Link-Layer Address option: Including this option whenever possible is RECOMMENDED. The load balancing use case in Section 6.2.3 of [RFC4861] is out of scope for this document and is not generally expected to be applicable. The benefit of including this option is that it eliminates the need to do neighbor discovery on the SNAC router's link-local address in order to get its link-layer address.
 - MTU option: the SNAC router is not managing the link, and hence SHOULD NOT send this option.
 - Prefix Information options: when there is no suitable prefix (See Section 5.1.1) on the infrastructure link, some SNAC router will need to send a PIO. However, unless they are able to cooperate in choosing a PIO, only one SNAC routers will send it PIO. How this decision is made is described in Section 5.1.2. When a SNAC router sends this option, the following settings apply:

- o In the 'L' flag bit (on-link): 1.
- o In the 'A' flag bit (Autonomous address configuration): 1
- o In the Valid Lifetime field: normally STUB_PROVIDED_PREFIX_LIFETIME (see Section 3), but see Section 5.1.2.5.
- o In the Preferred Lifetime field: normally STUB_PROVIDED_PREFIX_LIFETIME (see Section 3), but see Section 5.1.2.5.
- Route Information Option: an active SNAC router always provides a Route Information Option for each prefix that is valid on the stub network. This provides a route from the infrastructure network to the stub network. The following settings apply:
 - o Prefix Length: 64
 - o Route Preference: low
 - o Route Lifetime: STUB_NETWORK_ROUTE_LIFETIME (TBD: what about deprecated prefixes? Add reference to new proposed text that addresses issue #67 on github)
 - o Prefix: the prefix advertised on the stub network

It is expected that all RA options for a SNAC router will fit in a single RA. Therefore, SNAC routers are not expected to send multiple RAs with different information other than to announce that some information previously advertised has changed.

Appendix C. Router Advertisements on the stub network

A SNAC router sends periodic as well as solicited Router Advertisements filled with the following values consistent with the message format given in Section 4.2 of [RFC4861]:

- * Router Lifetime: The SNAC router can be a default router on the stub network (see xref target="snac-reachability" TBD fixref).
- * SNAC routers do not provide DHCP service on the stub network. Therefore, the 'M' and 'O' flag bits MUST be zero.
- * The 'SNAC router' flag bit xref target="I-D.ietf-6man-snac-router-bit" TBD waitRef MUST be 0.
- * In the Cur Hop Limit field: 0

- * In the Reachable Time field: 0
- * In the Retrans Timer field: 0
- * In the options, the SNAC router may send options as appropriate.
 - Source Link-Layer Address option: Including this option whenever possible is RECOMMENDED. The load balancing use case in Section 6.2.3 of [RFC4861] is out of scope for this document and is not generally expected to be applicable. The benefit of including this option is that it eliminates the need to do neighbor discovery on the SNAC router's link-local address in order to get its link-layer address.
 - MTU option: the SNAC router is managing the link, and hence MAY send this option.
 - Some SNAC router will need to send a PIO. Normally, only one SNAC router will send a PIO. How this decision is made is described in Section 5.2. When a SNAC router sends this option, the following settings apply:
 - o In the 'L' flag bit (on-link): 1.
 - o In the 'A' flag bit (Autonomous address configuration): 1
 - o In the Valid Lifetime field: normally STUB_PROVIDED_PREFIX_LIFETIME (see Section 3), but see Section 5.1.2.5.
 - o In the Preferred Lifetime field: normally STUB_PROVIDED_PREFIX_LIFETIME (see Section 3), but see Section 5.1.2.5.
 - Route Information Option: when a SNAC router is not advertising a default route, it MUST include one or more RIO options in router advertisements on the stub network to provide reachability to infrastructure. This is discussed in Section 5.4. The following settings apply:
 - o Prefix Length: the length of the prefix covered by the route, not necessarily 64.
 - o Route Preference: low
 - o Route Lifetime: The lifetime of the prefix on the infrastructure link, but no more than STUB_NETWORK_ROUTE_LIFETIME

- o Prefix: the prefix that is known to be reachable on the infrastructure network

Appendix D. Handling failure and change situations on a stub network

How a SNAC router handles situations of device failure, network failure or other changes on its stub network is outside the scope of the normative specification for a SNAC router. This handling depends on the specific stub network technology being used. This informative appendix provides guidance about the expected behavior and properties of the stub network with respect to failure and change situations, such that the interoperability goals (Section 1.1) and the usability goals (Section 1.2) can be satisfied.

A SNAC router that supports cooperation between multiple SNAC routers in the same stub network is expected to support the following basic failure and change situations by automatically adapting to the new situation:

- * A new SNAC router is added to the stub network.
- * A SNAC router is powered down, or removed from the stub network.
- * An existing SNAC router is powered up again, after a short (e.g. reboot) or long period of time.
- * A SNAC router fails and stops operating.
- * Connectivity in the stub network changes due to e.g. changing radio conditions, moved devices, or plugged/unplugged cables.

While the details of how a stub network technology supports these basic cases is out of scope of this document, some hints, suggestions and examples from current stub network technologies are discussed below.

Some technologies used for stub networks, for example Thread or 6LoWPAN wireless mesh networks, can produce partitioned networks, where what is notionally the same stub network winds up looking like two or more discrete links. Such partitions can form and rejoin over time as a result of either changes in radio propagation or the addition of, or removal of, or mobility of, devices on the mesh.

On stub networks that can partition, one way of detecting that a partition has occurred is to notice that the SNAC router that has advertised the on-link OSNR prefix for the stub network is no longer reachable via the stub network. A SNAC router that notices such a loss of reachability can take action in order to satisfy the

requirement in Section 5.2 that at least one SNAC router provides an OSNR prefix. How this requirement is satisfied is specific to the stub network technology used. For example, the SNAC router could autonomously decide to advertise its own OSNR prefix if it sees that no other SNAC router is advertising an OSNR prefix yet. Or, it could perform a coordination protocol with the other SNAC routers that it can still reach, to determine which of the SNAC routers should provide the OSNR prefix next.

An implication of this is that when such a partition forms, the same OSNR prefix cannot be advertised on both partitions, since this will result in ambiguous routing. This problem is already addressed by the requirement that each SNAC router generate its own ULA site prefix (see Section 5.2.2).

When partitions of this type occur, they may also heal at a later time. When a stub network heals in a situation where two SNAC routers have both been advertising an OSNR prefix on their respective partitions, it will now appear that there are two OSNR prefixes on the same stub network.

How the case of two or more OSNR prefixes on the same stub network is handled, is specific to the stub network technology. Some technologies may easily handle multiple OSNR prefixes, while other more constrained network technologies may need to apply a maximum to the number of OSNR prefixes for resource/efficiency reasons. See Section 5.2.3 for more discussion on such single-prefix and multiple-prefix constraints. While that section has DHCPv6-specific requirements only, the general issue needs to be resolved by a stub network technology also for deployments in which DHCPv6-PD is not available or deployments with mixed DHCPv6/ULA based OSNR prefixes.

As an example that can be used in a constrained stub network: a feasible strategy is for each SNAC router to perform a numeric comparison between the multiple OSNR prefixes and let the numerically lowest prefix/prefixes "win". The prefixes that don't win are deprecated. This has the benefit that global DHCPv6-PD delegated OSNR prefixes are selected in favor of the numerically higher ULA link prefixes, thus supporting the SNAC interoperability goal of IP connectivity to the Internet.

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