Network Working Group
Internet-Draft
Intended status: Informational
Expires: April 25, 2014

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October 22, 2013

IPv6 Home Networking Architecture Principles
draft-ietf-homenet-arch-11

Abstract

This text describes evolving networking technology within residential home networks with increasing numbers of devices and a trend towards increased internal routing. The goal of this document is to define a general architecture for IPv6-based home networking, describing the associated principles, considerations and requirements. The text briefly highlights specific implications of the introduction of IPv6 for home networking, discusses the elements of the architecture, and suggests how standard IPv6 mechanisms and addressing can be employed in home networking. The architecture describes the need for specific protocol extensions for certain additional functionality. It is assumed that the IPv6 home network is not actively managed, and runs as an IPv6-only or dual-stack network. There are no recommendations in this text for the IPv4 part of the network.

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1. Introduction

This document focuses on evolving networking technology within residential home networks with increasing numbers of devices and a trend towards increased internal routing, and the associated challenges with their deployment and operation. There is a growing trend in home networking for the proliferation of networking technology through an increasingly broad range of devices and media. This evolution in scale and diversity sets requirements on IETF protocols. Some of these requirements relate to the introduction of IPv6, others to the introduction of specialised networks for home automation and sensors.

While at the time of writing some complex home network topologies exist, most are relatively simple single subnet networks, and ostensibly operate using just IPv4. While there may be IPv6 traffic within the network, e.g., for service discovery, the homenet is provisioned by the ISP as an IPv4 network. Such networks also typically employ solutions that should be avoided, such as private [RFC1918] addressing with (cascaded) network address translation (NAT) [RFC3022], or they may require expert assistance to set up.

In contrast, emerging IPv6-capable home networks are very likely to have multiple internal subnets, e.g., to facilitate private and guest networks, heterogeneous link layers, and smart grid components, and have enough address space available to allow every device to have a globally unique address. This implies that internal routing functionality is required, and that the homenet's ISP both provides a large enough prefix to allocate a prefix to each subnet, and that a method is supported for such prefixes to be delegated efficiently to those subnets.

It is not practical to expect home users to configure their networks. Thus the assumption of this document is that the homenet is as far as possible self-organising and self-configuring, i.e., it should function without pro-active management by the residential user.

The architectural constructs in this document are focused on the problems to be solved when introducing IPv6, with an eye towards a better result than what we have today with IPv4, as well as aiming at a more consistent solution that addresses as many of the identified requirements as possible. The document aims to provide the basis and guiding principles for how standard IPv6 mechanisms and addressing [RFC2460] [RFC4291] can be employed in home networking, while coexisting with existing IPv4 mechanisms. In emerging dual-stack home networks it is vital that introducing IPv6 does not adversely affect IPv4 operation. We assume that the IPv4 network architecture in home networks is what it is, and can not be modified by new

recommendations. This document does not discuss how IPv4 home networks provision or deliver support for multiple subnets. It should not be assumed that any future new functionality created with IPv6 in mind will be backward-compatible to include IPv4 support. Further, future deployments, or specific subnets within an otherwise dual-stack home network, may be IPv6-only, in which case considerations for IPv4 impact would not apply.

This document proposes a baseline homenet architecture, using protocols and implementations that are as far as possible proven and robust. The scope of the document is primarily the network layer technologies that provide the basic functionality to enable addressing, connectivity, routing, naming and service discovery. While it may, for example, state that homenet components must be simple to deploy and use, it does not discuss specific user interfaces, nor does it discuss specific physical, wireless or data-link layer considerations.

[RFC6204] defines basic requirements for customer edge routers (CERs). This document has recently been updated with the definition of requirements for specific transition tools on the CER in [I-D.ietf-v6ops-6204bis], specifically DS-Lite [RFC6333] and 6rd [RFC5969]. Such detailed specification of CER devices is considered out of scope of this architecture document, and we assume that any required update of the CER device specification as a result of adopting this architecture will be handled as separate and specific updates to these existing documents. Further, the scope of this text is the internal homenet, and thus specific features on the WAN side of the CER are out of scope for this text.

1.1. Terminology and Abbreviations

In this section we define terminology and abbreviations used throughout the text.

- Border: a point, typically resident on a router, between two networks, e.g., between the main internal homenet and a guest network. This defines point(s) at which filtering and forwarding policies for different types of traffic may be applied.

- CER: Customer Edge Router: A border router intended for use in a homenet, which connects the homenet to a service provider network.

- FQDN: Fully Qualified Domain Name. A globally unique name.

- Guest network: A part of the home network intended for use by visitors or guests to the home(net). Devices on the guest network may typically not see or be able to use all services in the

home(net).

- Homenet: A home network, comprising host and router equipment, with one or more CERs providing connectivity to service provider network(s).

- Internet Service Provider (ISP): an entity that provides access to the Internet. In this document, a service provider specifically offers Internet access using IPv6, and may also offer IPv4 Internet access. The service provider can provide such access over a variety of different transport methods such as DSL, cable, wireless, and others.

- LLN: Low-power and lossy network.

- LQDN: Locally Qualified Domain Name. A name local to the homenet.

- NAT: Network Address Translation. Typically referring to IPv4 Network Address and Port Translation (NAPT) [RFC3022].

- NPTv6: Network Prefix Translation for IPv6 [RFC6296].

- PCP: Port Control Protocol [RFC6887].

- Realm: a network delimited by a defined border. A guest network within a homenet may form one realm.

- 'Simple Security'. Defined in [RFC4864] and expanded further in [RFC6092]; describes recommended perimeter security capabilities for IPv6 networks.

- ULA: IPv6 Unique Local Address [RFC4193].

- VM: Virtual machine.

2. Effects of IPv6 on Home Networking

While IPv6 resembles IPv4 in many ways, there are some notable differences in the way it may typically be deployed. It changes address allocation principles, making multi-addressing the norm, and, through the vastly increased address space, allows globally unique IP addresses to be used for all devices in a home network. This section presents an overview of some of the key implications of the introduction of IPv6 for home networking, that are simultaneously both promising and problematic.

2.1. Multiple subnets and routers

While simple layer 3 topologies involving as few subnets as possible are preferred in home networks, the incorporation of dedicated (routed) subnets remains necessary for a variety of reasons. For instance, an increasingly common feature in modern home routers is the ability to support both guest and private network subnets. Likewise, there may be a need to separate home automation or corporate extension LANs (whereby a home worker can have their corporate network extended into the home using a virtual private network, commonly presented as one port on an Ethernet device) from the main Internet access network, or different subnets may in general be associated with parts of the homenet that have different routing and security policies. Further, link layer networking technology is poised to become more heterogeneous, as networks begin to employ both traditional Ethernet technology and link layers designed for low-power and lossy networks (LLNs), such as those used for certain types of sensor devices. Constraining the flow of certain traffic from Ethernet links to much lower capacity links thus becomes an important topic.

The introduction of IPv6 for home networking makes it possible for every home network to be delegated enough address space from its ISP to provision globally unique prefixes for each such subnet in the home. While the number of addresses in a standard /64 IPv6 prefix is practically unlimited, the number of prefixes available for assignment to the home network is not. As a result the growth inhibitor for the home network shifts from the number of addresses to the number of prefixes offered by the provider; this topic is discussed in [RFC6177] (BCP 157), which recommends that "end sites always be able to obtain a reasonable amount of address space for their actual and planned usage".

The addition of routing between subnets raises a number of issues. One is a method by which prefixes can be efficiently allocated to each subnet, without user intervention. Another is the issue of how to extend mechanisms such as zero configuration service discovery which currently only operate within a single subnet using link-local traffic. In a typical IPv4 home network, there is only one subnet, so such mechanisms would normally operate as expected. For multi-subnet IPv6 home networks there are two broad choices to enable such protocols to work across the scope of the entire homenet; extend existing protocols to work across that scope, or introduce proxies for existing link layer protocols. This topic is discussed in Section 3.7.

2.2. Global addressability and elimination of NAT

The possibility for direct end-to-end communication on the Internet to be restored by the introduction of IPv6 is on the one hand an incredible opportunity for innovation and simpler network operation, but on the other hand it is also a concern as it potentially exposes nodes in the internal networks to receipt of unwanted and possibly malicious traffic from the Internet.

With devices and applications able to talk directly to each other when they have globally unique addresses, there may be an expectation of improved host security to compensate for this. It should be noted that many devices may (for example) ship with default settings that make them readily vulnerable to compromise by external attackers if globally accessible, or may simply not have robustness designed-in because it was either assumed such devices would only be used on private networks or the device itself doesn't have the computing power to apply the necessary security methods. In addition, the upgrade cycle for devices (or their firmware) may be slow, and/or lack auto-update mechanisms.

It is thus important to distinguish between addressability and reachability. While IPv6 offers global addressability through use of globally unique addresses in the home, whether devices are globally reachable or not would depend on any firewall or filtering configuration, and not, as is commonly the case with IPv4, the presence or use of NAT. In this respect, IPv6 networks may or may not have filters applied at their borders to control such traffic, i.e., at the homenet CER. [RFC4864] and [RFC6092] discuss such filtering, and the merits of 'default allow' against 'default deny' policies for external traffic initiated into a homenet. This document takes no position on which mode is the default, but assumes the choice for the homenet to use either mode would be available.

This topic is discussed further in Section 3.6.1.

2.3. Multi-Addressing of devices

In an IPv6 network, devices will often acquire multiple addresses, typically at least a link-local address and one or more globally unique addresses. Where a homenet is multihomed, a device would typically receive a globally unique address (GUA) from within the delegated prefix from each upstream ISP. Devices may also have an IPv4 address if the network is dual-stack, an IPv6 Unique Local Address (ULA) [RFC4193] (see below), and one or more IPv6 Privacy Addresses [RFC4941].

It should thus be considered the norm for devices on IPv6 home

networks to be multi-addressed, and to need to make appropriate address selection decisions for the candidate source and destination address pairs for any given connection. Default Address Selection for IPv6 [RFC6724] provides a solution for this, though it may face problems in the event of multihoming where, as described above, nodes will be configured with one address from each upstream ISP prefix. In such cases the presence of upstream BCP 38 [RFC2827] ingress filtering requires multi-addressed nodes to select the correct source address to be used for the corresponding uplink. A challenge here is that the node may not have the information it needs to make that decision based on addresses alone. We discuss this challenge in Section 3.2.4.

2.4. Unique Local Addresses (ULAs)

[RFC4193] defines Unique Local Addresses (ULAs) for IPv6 that may be used to address devices within the scope of a single site. Support for ULAs for IPv6 CERs is described in [RFC6204]. A home network running IPv6 should deploy ULAs alongside its globally unique prefix(es) to allow stable communication between devices (on different subnets) within the homenet where that externally allocated globally unique prefix may change over time, e.g., due to renumbering within the subscriber's ISP, or where external connectivity may be temporarily unavailable. A homenet using provider-assigned global addresses is exposed to its ISP renumbering the network to a much larger degree than before whereas, for IPv4, NAT isolated the user against ISP renumbering to some extent.

While setting up a network there may be a period where it has no external connectivity, in which case ULAs would be required for inter-subnet communication. In the case where home automation networks are being set up in a new home/deployment (as early as during construction of the home), such networks will likely need to use their own /48 ULA prefix. Depending upon circumstances beyond the control of the owner of the homenet, it may be impossible to renumber the ULA used by the home automation network so routing between ULA /48s may be required. Also, some devices, particularly constrained devices, may have only a ULA (in addition to a link-local), while others may have both a GUA and a ULA.

Note that unlike private IPv4 RFC 1918 space, the use of ULAs does not imply use of an IPv6 equivalent of a traditional IPv4 NAT [RFC3022], or of NPTv6 prefix-based NAT [RFC6296]. When an IPv6 node in a homenet has both a ULA and a globally unique IPv6 address, it should only use its ULA address internally, and use its additional globally unique IPv6 address as a source address for external communications. This should be the natural behaviour given support for Default Address Selection for IPv6 [RFC6724]. By using such

globally unique addresses between hosts and devices in remote networks, the architectural cost and complexity, particularly to applications, of NAT or NPTv6 translation is avoided. As such, neither IPv6 NAT or NPTv6 is recommended for use in the homenet architecture. Further, the homenet border router(s) should filter packets with ULA source/destination addresses as discussed in Section 3.4.2.

Devices in a homenet may be given only a ULA as a means to restrict reachability from outside the homenet. ULAs can be used by default for devices that, without additional configuration (e.g., via a web interface), would only offer services to the internal network. For example, a printer might only accept incoming connections on a ULA until configured to be globally reachable, at which point it acquires a global IPv6 address and may be advertised via a global name space.

Where both a ULA and a global prefix are in use, the ULA source address is used to communicate with ULA destination addresses when appropriate, i.e., when the ULA source and destination lie within the /48 ULA prefix(es) known to be used within the same homenet. In cases where multiple /48 ULA prefixes are in use within a single homenet (perhaps because multiple homenet routers each independently auto-generate a /48 ULA prefix and then share prefix/routing information), utilising a ULA source address and a ULA destination address from two disjoint internal ULA prefixes is preferable to using GUAs.

While a homenet should operate correctly with two or more /48 ULAs enabled, a mechanism for the creation and use of a single /48 ULA prefix is desirable for addressing consistency and policy enforcement.

A counter-argument to using ULAs is that it is undesirable to aggressively deprecate global prefixes for temporary loss of connectivity, so for a host to lose its global address there would have to be a connection breakage longer than the lease period, and even then, deprecating prefixes when there is no connectivity may not be advisable. However, it is assumed in this architecture that homenets should support and use ULAs.

2.5. Avoiding manual configuration of IP addresses

Some IPv4 home networking devices expose IPv4 addresses to users, e.g., the IPv4 address of a home IPv4 CER that may be configured via a web interface. In potentially complex future IPv6 homenets, users should not be expected to enter IPv6 literal addresses in devices or applications, given their much greater length and the apparent randomness of such addresses to a typical home user. Thus, even for

the simplest of functions, simple naming and the associated (minimal, and ideally zero configuration) discovery of services is imperative for the easy deployment and use of homenet devices and applications.

2.6. IPv6-only operation

It is likely that IPv6-only networking will be deployed first in new home network deployments, often refered to as 'greenfield' scenarios, where there is no existing IPv4 capability, or perhaps as one element of an otherwise dual-stack network. Running IPv6-only adds additional requirements, e.g., for devices to get configuration information via IPv6 transport (not relying on an IPv4 protocol such as IPv4 DHCP), and for devices to be able to initiate communications to external devices that are IPv4-only.

Some specific transition technologies which may be deployed by the homenet's ISP are discussed in [I-D.ietf-v6ops-6204bis]. In addition, certain other functions may be desirable on the CER, e.g., to access content in the IPv4 Internet, NAT64 [RFC6144] and DNS64 [RFC6145] may be applicable.

The widespread availability of robust solutions to these types of requirements will help accelerate the uptake of IPv6-only homenets. The specifics of these are however beyond the scope of this document, especially those functions that reside on the CER.

3. Homenet Architecture Principles

The aim of this text is to outline how to construct advanced IPv6-based home networks involving multiple routers and subnets using standard IPv6 addressing and protocols [RFC2460] [RFC4291] as the basis. As described in Section 3.1, solutions should as far as possible re-use existing protocols, and minimise changes to hosts and routers, but some new protocols, or extensions, are likely to be required. In this section, we present the elements of the proposed home networking architecture, with discussion of the associated design principles.

In general, home network equipment needs to be able to operate in networks with a range of different properties and topologies, where home users may plug components together in arbitrary ways and expect the resulting network to operate. Significant manual configuration is rarely, if at all, possible, or even desirable given the knowledge level of typical home users. Thus the network should, as far as possible, be self-configuring, though configuration by advanced users should not be precluded.

The homenet needs to be able to handle or provision at least

- Routing
- Prefix configuration for routers
- Name resolution
- Service discovery
- Network security

The remainder of this document describes the principles by which the homenet architecture may deliver these properties.

3.1. General Principles

There is little that the Internet standards community can do about the physical topologies or the need for some networks to be separated at the network layer for policy or link layer compatibility reasons. However, there is a lot of flexibility in using IP addressing and inter-networking mechanisms. This text discusses how such flexibility should be used to provide the best user experience and ensure that the network can evolve with new applications in the future. The principles described in this text should be followed when designing homenet protocol solutions.

3.1.1. Reuse existing protocols

It is desirable to reuse existing protocols where possible, but at the same time to avoid consciously precluding the introduction of new or emerging protocols. A generally conservative approach, giving weight to running (and available) code, is preferable. Where new protocols are required, evidence of commitment to implementation by appropriate vendors or development communities is highly desirable. Protocols used should be backwardly compatible, and forward compatible where changes are made.

3.1.2. Minimise changes to hosts and routers

In order to maximise deployability of new homenets, where possible any requirement for changes to hosts and routers should be minimised, though solutions which, for example, incrementally improve capability with host or router changes may be acceptable. There may be cases where changes are unavoidable, e.g., to allow a given homenet routing protocol to be self-configuring.

3.2. Homenet Topology

This section considers homenet topologies, and the principles that may be applied in designing an architecture to support as wide a range of such topologies as possible.

3.2.1. Supporting arbitrary topologies

There should ideally be no built-in assumptions about the topology in home networks, as users are capable of connecting their devices in 'ingenious' ways. Thus arbitrary topologies and arbitrary routing will need to be supported, or at least the failure mode for when the user makes a mistake should be as robust as possible, e.g., de-activating a certain part of the infrastructure to allow the rest to operate. In such cases, the user should ideally have some useful indication of the failure mode encountered.

There should be no topology scenarios which cause loss of connectivity, except when the user creates a physical island within the topology. Some potentially pathological cases that can be created include bridging ports of a router together, however this case can be detected and dealt with by the router. Loops within a routed topology are in a sense good in that they offer redundancy. Bridging loops can be dangerous but are also detectable when a switch learns the MAC of one of its interfaces on another or runs a spanning tree or link state protocol. It is only loops using simple repeaters that are truly pathological.

The topology of the homenet may change over time, due to the addition or removal of equipment, but also due to temporary failures or connectivity problems. In some cases this may lead to, for example, a multihomed homenet being split into two isolated homenets, or, after such a fault is remedied, two isolated parts reconfiguring back to a single network.

3.2.2. Network topology models

Most IPv4 home network models at the time of writing tend to be relatively simple, typically a single NAT router to the ISP and a single internal subnet but, as discussed earlier, evolution in network architectures is driving more complex topologies, such as the separation of guest and private networks. There may also be some cascaded IPv4 NAT scenarios, which we mention in the next section. For IPv6 homenets, the Network Architectures described in [RFC6204] and its successor [I-D.ietf-v6ops-6204bis] should, as a minimum, be supported.

There are a number of properties or attributes of a home network that

we can use to describe its topology and operation. The following properties apply to any IPv6 home network:

- Presence of internal routers. The homenet may have one or more internal routers, or may only provide subnetting from interfaces on the CER.

- Presence of isolated internal subnets. There may be isolated internal subnets, with no direct connectivity between them within the homenet (with each having its own external connectivity). Isolation may be physical, or implemented via IEEE 802.1q VLANs. The latter is however not something a typical user would be expected to configure.

- Demarcation of the CER. The CER(s) may or may not be managed by the ISP. If the demarcation point is such that the customer can provide or manage the CER, its configuration must be simple. Both models must be supported.

Various forms of multihoming are likely to become more prevalent with IPv6 home networks, where the homenet may have two or more external ISP connections, as discussed further below. Thus the following properties should also be considered for such networks:

- Number of upstream providers. The majority of home networks today consist of a single upstream ISP, but it may become more common in the future for there to be multiple ISPs, whether for resilience or provision of additional services. Each would offer its own prefix. Some may or may not provide a default route to the public Internet.

- Number of CERs. The homenet may have a single CER, which might be used for one or more providers, or multiple CERs. The presence of multiple CERs adds additional complexity for multihoming scenarios, and protocols like PCP that may need to manage connection-oriented state mappings on the same CER as used for subsequent traffic flows.

In the following sections we give some examples of the types of homenet topologies we may see in the future. This is not intended to be an exhaustive or complete list, rather an indicative one to facilitate the discussion in this text.

3.2.2.1. A: Single ISP, Single CER, Internal routers

Figure 1 shows a home network with multiple local area networks. These may be needed for reasons relating to different link layer technologies in use or for policy reasons, e.g., classic Ethernet in

one subnet and a LLN link layer technology in another. In this example there is no single router that a priori understands the entire topology. The topology itself may also be complex, and it may not be possible to assume a pure tree form, for instance (because home users may plug routers together to form arbitrary topologies including loops).

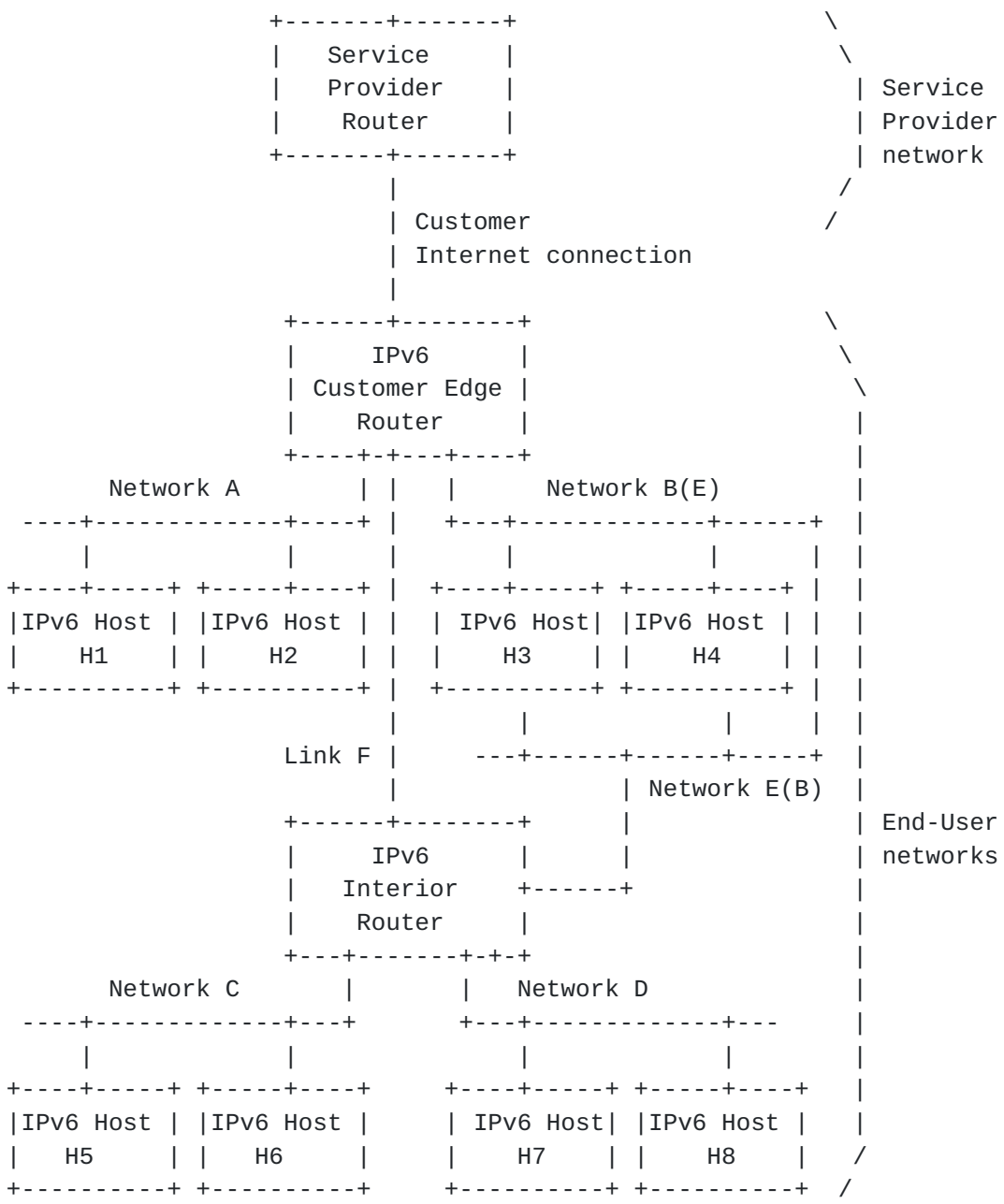

Figure 1

In this diagram there is one CER. It has a single uplink interface. It has three additional interfaces connected to Network A, Link F, and Network B. IPv6 Internal Router (IR) has four interfaces connected to Link F, Network C, Network D and Network E. Network B and Network E have been bridged, likely inadvertently. This could be as a result of connecting a wire between a switch for Network B and a switch for Network E.

Any of logical Networks A through F might be wired or wireless.

Where multiple hosts are shown, this might be through one or more physical ports on the CER or IPv6 (IR), wireless networks, or through one or more layer-2 only Ethernet switches.

3.2.2.2. B: Two ISPs, Two CERs, Shared subnet

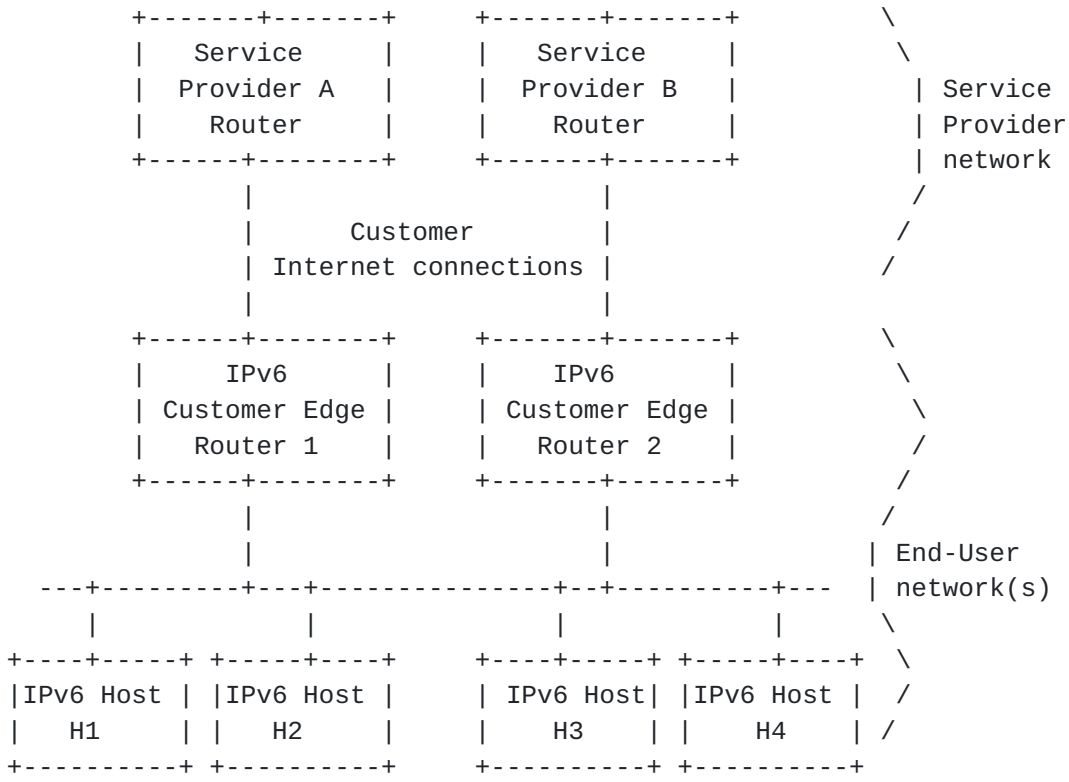

Figure 2

Figure 2 illustrates a multihomed homenet model, where the customer has connectivity via CER1 to ISP A and via CER2 to ISP B. This example shows one shared subnet where IPv6 nodes would potentially be multihomed and receive multiple IPv6 global prefixes, one per ISP. This model may also be combined with that shown in Figure 1 to create a more complex scenario with multiple internal routers. Or the above shared subnet may be split in two, such that each CER serves a separate isolated subnet, which is a scenario seen with some IPv4 networks today.

3.2.2.3. C: Two ISPs, One CER, Shared subnet

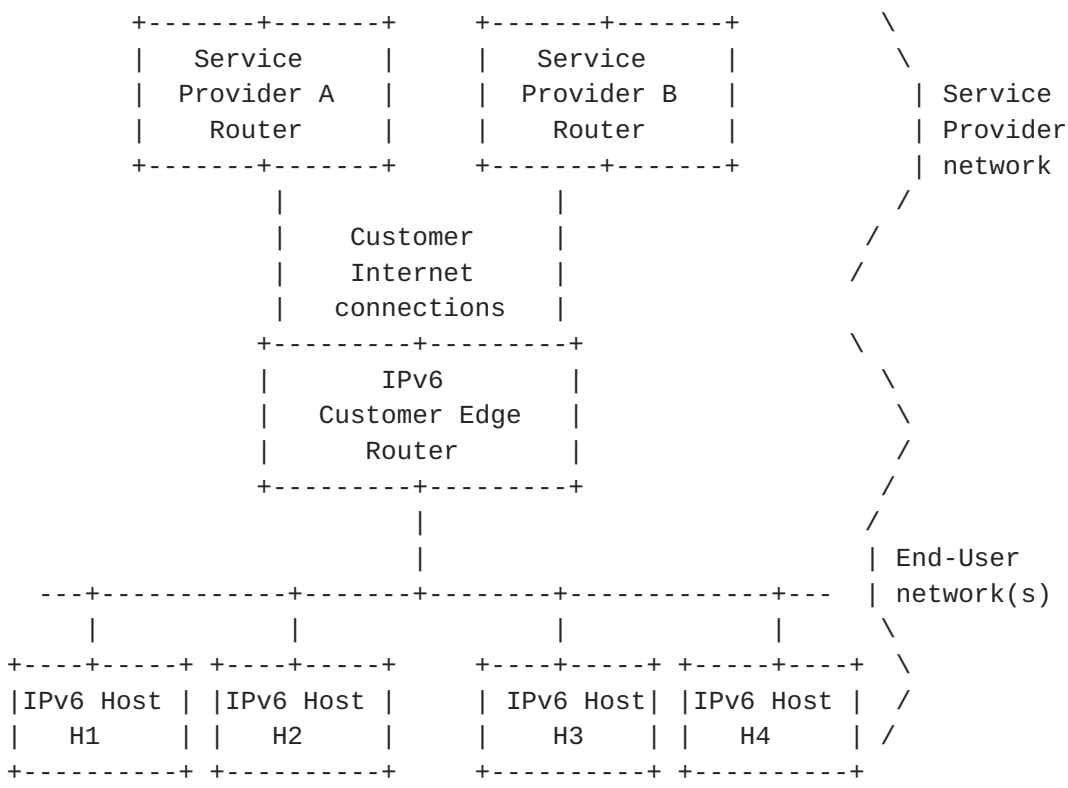

Figure 3

Figure 3 illustrates a model where a home network may have multiple connections to multiple providers or multiple logical connections to the same provider, with shared internal subnets.

In general, while the architecture may focus on likely common topologies, it should not preclude any arbitrary topology from being constructed.

3.2.3. Dual-stack topologies

It is expected that most homenet deployments will for the immediate future be dual-stack IPv4/IPv6. In such networks it is important not to introduce new IPv6 capabilities that would cause a failure if used alongside IPv4+NAT, given that such dual-stack homenets will be commonplace for some time. That said, it is desirable that IPv6 works better than IPv4 in as many scenarios as possible. Further, the homenet architecture must operate in the absence of IPv4.

A general recommendation is to follow the same topology for IPv6 as is used for IPv4, but not to use NAT. Thus there should be routed

IPv6 where an IPv4 NAT is used and, where there is no NAT, routing or bridging may be used. Routing may have advantages when compared to bridging together high speed and lower speed shared media, and in addition bridging may not be suitable for some networks, such as ad-hoc mobile networks.

In some cases IPv4 home networks may feature cascaded NATs. End users are frequently unaware that they have created such networks as 'home routers' and 'home switches' are frequently confused. In addition, there are cases where NAT routers are included within Virtual Machine Hypervisors, or where Internet connection sharing services have been enabled. This document applies equally to such hidden NAT 'routers'. IPv6 routed versions of such cases will be required. We should thus also note that routers in the homenet may not be separate physical devices; they may be embedded within other devices.

3.2.4. Multihoming

A homenet may be multihomed to multiple providers, as the network models above illustrate. This may either take a form where there are multiple isolated networks within the home or a more integrated network where the connectivity selection needs to be dynamic. Current practice is typically of the former kind, but the latter is expected to become more commonplace.

In the general homenet architecture, multihomed hosts should be multi-addressed with a global IPv6 address from the global prefix delegated from each ISP they communicate with or through. When such multi-addressing is in use, hosts need some way to pick source and destination address pairs for connections. A host may choose a source address to use by various methods, most commonly [RFC6724]. Applications may of course do different things, and this should not be precluded.

For the single CER Network Model C illustrated above, multihoming may be offered by source-based routing at the CER. With multiple exit routers, as in CER Network Model B, the complexity rises. Given a packet with a source address on the home network, the packet must be routed to the proper egress to avoid BCP 38 ingress filtering if exiting through the wrong ISP. It is highly desirable that the packet is routed in the most efficient manner to the correct exit, though as a minimum requirement the packet should not be dropped.

The homenet architecture should support both the above models, i.e., one or more CERs. However, the general multihoming problem is broad, and solutions suggested to date within the IETF have included complex architectures for monitoring connectivity, traffic engineering,

identifier-locator separation, connection survivability across multihoming events, and so on. It is thus important that the homenet architecture should as far as possible minimise the complexity of any multihoming support.

An example of such a 'simpler' approach has been documented in [I-D.ietf-v6ops-ipv6-multihoming-without-ipv6nat]. Alternatively a flooding/routing protocol could potentially be used to pass information through the homenet, such that internal routers and ultimately end hosts could learn per-prefix configuration information, allowing better address selection decisions to be made. However, this would imply router and, most likely, host changes. Another avenue is to introduce support throughout the homenet for routing which is based on the source as well as the destination address of each packet. While greatly improving the 'intelligence' of routing decisions within the homenet, such an approach would require relatively significant router changes but avoid host changes.

As explained previously, while NPTv6 has been proposed for providing multi-homing support in networks, its use is not recommended in the homenet architecture.

It should be noted that some multihoming scenarios may see one upstream being a "walled garden", and thus only appropriate for connectivity to the services of that provider; an example may be a VPN service that only routes back to the enterprise business network of a user in the homenet. As per [RFC3002] (section 4.2.1) we do not specifically target walled garden multihoming as a goal of this document.

The homenet architecture should also not preclude use of host or application-oriented tools, e.g., Shim6 [RFC5533], MPTCP [RFC6824] or Happy Eyeballs [RFC6555]. In general, any incremental improvements obtained by host changes should give benefit for the hosts introducing them, but not be required.

3.3. A Self-Organising Network

The home network infrastructure should be naturally self-organising and self-configuring under different circumstances relating to the connectivity status to the Internet, number of devices, and physical topology. At the same time, it should be possible for advanced users to manually adjust (override) the current configuration.

While a goal of the homenet architecture is for the network to be as self-organising as possible, there may be instances where some manual configuration is required, e.g., the entry of a cryptographic key to apply wireless security, or to configure a shared routing secret.

The latter may be relevant when considering how to bootstrap a routing configuration. It is highly desirable that the number of such configurations is minimised.

3.3.1. Differentiating neighbouring homenets

It is important that self-configuration with 'unintended' devices is avoided. There should be a way for a user to administratively assert in a simple way whether or not a device belongs to a homenet. The goal is to allow the establishment of borders, particularly between two adjacent homenets, and to avoid unauthorised devices from participating in the homenet. Such an authorisation capability may need to operate through multiple hops in the homenet.

The homenet should thus support a way for a homenet owner to claim ownership of their devices in a reasonably secure way. This could be achieved by a pairing mechanism, by for example pressing buttons simultaneously on an authenticated and a new homenet device, or by an enrolment process as part of an autonomic networking environment.

3.3.2. Largest practical subnets

Today's IPv4 home networks generally have a single subnet, and early dual-stack deployments have a single congruent IPv6 subnet, possibly with some bridging functionality. More recently, some vendors have started to introduce 'home' and 'guest' functions, which in IPv6 would be implemented as two subnets.

Future home networks are highly likely to have one or more internal routers and thus need multiple subnets, for the reasons described earlier. As part of the self-organisation of the network, the homenet should subdivide itself into the largest practical subnets that can be constructed within the constraints of link layer mechanisms, bridging, physical connectivity, and policy, and where applicable performance or other criteria. In such subdivisions the logical topology may not necessarily match the physical topology. This text does not, however, make recommendations on how such subdivision should occur. It is expected that subsequent documents will address this problem.

While it may be desirable to maximise the chance of link-local protocols operating across a homenet by maximising the size of a subnet, multi-subnet home networks are inevitable, so their support must be included.

3.3.3. Handling varying link technologies

Homenets tend to grow organically over many years, and a homenet will typically be built over link-layer technologies from different generations. Current homenets typically use links ranging from 1Mbit/s up to 1Gbit/s, which is a three orders of magnitude throughput discrepancy. We expect this discrepancy to widen further as both high-speed and low-power technologies are deployed.

Homenet protocols should be designed to deal well with interconnecting links of very different throughputs. In particular, flows local to a link should not be flooded throughout the homenet, even when sent over multicast, and, whenever possible, the homenet protocols should be able to choose the faster links and avoid the slower ones.

Links (particularly wireless links) may also have limited numbers of transmit opportunities (txops), and there is a clear trend driven by both power and downward compatibility constraints toward aggregation of packets into these limited txops while increasing throughput. Transmit opportunities may be a system's scarcest resource and therefore also strongly limit actual throughput available.

3.3.4. Homenet realms and borders

The homenet will need to be aware of the extent of its own 'site', which will, for example, define the borders for ULA and site scope multicast traffic, and may require specific security policies to be applied. The homenet will have one or more such borders with external connectivity providers.

A homenet will most likely also have internal borders between internal realms, e.g., a guest realm or a corporate network extension realm. It should be possible to automatically discover these borders, which will determine, for example, the scope of where network prefixes, routing information, network traffic, service discovery and naming may be shared. The default mode internally should be to share everything.

It is expected that a realm would span at least an entire subnet, and thus the borders lie at routers which receive delegated prefixes within the homenet. It is also desirable, for a richer security model, that hosts are able to make communication decisions based on available realm and associated prefix information in the same way that routers at realm borders can.

A simple homenet model may just consider three types of realm and the borders between them, namely the internal homenet, the ISP and a

guest network. In this case the borders will include that from the homenet to the ISP, that from the guest network to the ISP, and that from the homenet to the guest network. Regardless, it should be possible for additional types of realms and borders to be defined, e.g., for some specific LLN-based network, such as Smart Grid, and for these to be detected automatically, and for an appropriate default policy to be applied as to what type of traffic/data can flow across such borders.

It is desirable to classify the external border of the home network as a unique logical interface separating the home network from service provider network/s. This border interface may be a single physical interface to a single service provider, multiple layer 2 sub-interfaces to a single service provider, or multiple connections to a single or multiple providers. This border makes it possible to describe edge operations and interface requirements across multiple functional areas including security, routing, service discovery, and router discovery.

It should be possible for the homenet user to override any automatically determined borders and the default policies applied between them, the exception being that it may not be possible to override policies defined by the ISP at the external border.

3.3.5. Configuration information from the ISP

In certain cases, it may be useful for the homenet to get certain configuration information from its ISP. For example, the homenet DHCP server may request and forward some options that it gets from its upstream DHCP server, though the specific of the options may vary across deployments. There is potential complexity here of course should the homenet be multihomed.

3.4. Homenet Addressing

The IPv6 addressing scheme used within a homenet must conform to the IPv6 addressing architecture [RFC4291]. In this section we discuss how the homenet needs to adapt to the prefixes made available to it by its upstream ISP, such that internal subnets, hosts and devices can obtain the and configure the necessary addressing information to operate.

3.4.1. Use of ISP-delegated IPv6 prefixes

Discussion of IPv6 prefix allocation policies is included in [RFC6177]. In practice, a homenet may receive an arbitrary length IPv6 prefix from its provider, e.g., /60, /56 or /48. The offered prefix may be stable or change from time to time; it is generally

expected that ISPs will offer relatively stable prefixes to their residential customers. Regardless, the home network needs to be adaptable as far as possible to ISP prefix allocation policies, and thus make no assumptions about the stability of the prefix received from an ISP, or the length of the prefix that may be offered.

However, if, for example, only a /64 is offered by the ISP, the homenet may be severely constrained or even unable to function. [RFC6177] (BCP 157) states that "a key principle for address management is that end sites always be able to obtain a reasonable amount of address space for their actual and planned usage, and over time ranges specified in years rather than just months. In practice, that means at least one /64, and in most cases significantly more. One particular situation that must be avoided is having an end site feel compelled to use IPv6-to-IPv6 Network Address Translation or other burdensome address conservation techniques because it could not get sufficient address space." This architecture document assumes that the guidance in the quoted text is being followed by ISPs.

There are many problems that would arise from a homenet not being offered a sufficient prefix size for its needs. Rather than attempt to contrive a method for a homenet to operate in a constrained manner when faced with insufficient prefixes, such as the use of subnet prefixes longer than /64 (which would break stateless address autonfiguration [RFC4862]), use of NPTv6, or falling back to bridging across potentially very different media, it is recommended that the receiving router instead enters an error state and issues appropriate warnings. Some consideration may need to be given to how such a warning or error state should best be presented to a typical home user.

Thus a homenet CER should request, for example via DHCP Prefix Delegation (DHCP PD) [RFC3633], that it would like a /48 prefix from its ISP, i.e., it asks the ISP for the maximum size prefix it might expect to be offered, even if in practice it may only be offered a /56 or /60. For a typical IPv6 homenet, it is not recommended that an ISP offer less than a /60 prefix, and it is highly preferable that the ISP offers at least a /56. It is expected that the allocated prefix to the homenet from any single ISP is a contiguous, aggregated one. While it may be possible for a homenet CER to issue multiple prefix requests to attempt to obtain multiple delegations, such behaviour is out of scope of this document.

The norm for residential customers of large ISPs may be similar to their single IPv4 address provision; by default it is likely to remain persistent for some time, but changes in the ISP's own provisioning systems may lead to the customer's IP (and in the IPv6 case their prefix pool) changing. It is not expected that ISPs will

generally support Provider Independent (PI) addressing for residential homenets.

When an ISP does need to restructure, and in doing so renumber its customer homenets, 'flash' renumbering is likely to be imposed. This implies a need for the homenet to be able to handle a sudden renumbering event which, unlike the process described in [RFC4192], would be a 'flag day" event, which means that a graceful renumbering process moving through a state with two active prefixes in use would not be possible. While renumbering can be viewed as an extended version of an initial numbering process, the difference between flash renumbering and an initial 'cold start' is the need to provide service continuity.

There may be cases where local law means some ISPs are required to change IPv6 prefixes (current IPv4 addresses) for privacy reasons for their customers. In such cases it may be possible to avoid an instant 'flash' renumbering and plan a non-flag day renumbering as per RFC 4192. Similarly, if an ISP has a planned renumbering process, it may be able to adjust lease timers, etc appropriately.

The customer may of course also choose to move to a new ISP, and thus begin using a new prefix. In such cases the customer should expect a discontinuity, and not only may the prefix change, but potentially also the prefix length if the new ISP offers a different default size prefix. The homenet may also be forced to renumber itself if significant internal 'replumbing' is undertaken by the user. Regardless, it's desirable that homenet protocols support rapid renumbering and that operational processes don't add unnecessary complexity for the renumbering process. Further, the introduction of any new homenet protocols should not make any form of renumbering any more complex than it already is.

Finally, the internal operation of the home network should also not depend on the availability of the ISP network at any given time, other than of course for connectivity to services or systems off the home network. This reinforces the use of ULAs for stable internal communication, and the need for a naming and service discovery mechanism that can operate independently within the homenet.

3.4.2. Stable internal IP addresses

The network should by default attempt to provide IP-layer connectivity between all internal parts of the homenet as well as to and from the external Internet, subject to the filtering policies or other policy constraints discussed later in the security section.

ULAs should be used within the scope of a homenet to support stable

routing and connectivity between subnets and hosts regardless of whether a globally unique ISP-provided prefix is available. In the case of a prolonged external connectivity outage, ULAs allow internal operations across routed subnets to continue. ULA addresses also allow constrained devices to create permanent relationships between IPv6 addresses, e.g., from a wall controller to a lamp, where symbolic host names would require additional non-volatile memory and updating global prefixes in sleeping devices might also be problematic.

As discussed previously, it would be expected that ULAs would normally be used alongside one or more global prefixes in a homenet, such that hosts become multi-addressed with both globally unique and ULA prefixes. ULAs should be used for all devices, not just those intended to only have internal connectivity. Default address selection would then enable ULAs to be preferred for internal communications between devices that are using ULA prefixes generated within the same homenet.

In cases where ULA prefixes are in use within a homenet but there is no external IPv6 connectivity (and thus no GUAs in use), recommendations ULA-5, L-3 and L-4 in RFC 6204 should be followed to ensure correct operation, in particular where the homenet may be dual-stack with IPv4 external connectivity. The use of the Route Information Option described in [RFC4191] provides a mechanism to advertise such more-specific ULA routes.

The use of ULAs should be restricted to the homenet scope through filtering at the border(s) of the homenet, as mandated by RFC 6204 requirement S-2.

Note that it is possible that in some cases multiple /48 ULA prefixes may be in use within the same homenet, e.g., when the network is being deployed, perhaps also without external connectivity. In cases where multiple ULA /48's are in use, hosts need to know that each /48 is local to the homenet, e.g., by inclusion in their local address selection policy table.

3.4.3. Internal prefix delegation

As mentioned above, there are various sources of prefixes. From the homenet perspective, a single global prefix from each ISP should be received on the border CER [RFC3633]. Where multiple CERs exist with multiple ISP prefix pools, it is expected that routers within the homenet would assign themselves prefixes from each ISP they communicate with/through. As discussed above, a ULA prefix should be provisioned for stable internal communications or for use on constrained/LLN networks.

The delegation or availability of a prefix pool to the homenet should allow subsequent internal autonomous delegation of prefixes for use within the homenet. Such internal delegation should not assume a flat or hierarchical model, nor should it make an assumption about whether the delegation of internal prefixes is distributed or centralised. The assignment mechanism should provide reasonable efficiency, so that typical home network prefix allocation sizes can accommodate all the necessary /64 allocations in most cases, and not waste prefixes. Further, duplicate assignment of multiple /64s to the same network should be avoided, and the network should behave as gracefully as possible in the event of prefix exhaustion (though the options in such cases may be limited).

Where the home network has multiple CERs and these are delegated prefix pools from their attached ISPs, the internal prefix delegation would be expected to be served by each CER for each prefix associated with it. Where ULAs are used, it is preferable that only one /48 ULA covers the whole homenet, from which /64's can be delegated to the subnets. In cases where two /48 ULAs are generated within a homenet, the network should still continue to function, meaning that hosts will need to determine that each ULA is local to the homenet.

Delegation within the homenet should result in each link being assigned a stable prefix that is persistent across reboots, power outages and similar short-term outages. The availability of persistent prefixes should not depend on the router boot order. The addition of a new routing device should not affect existing persistent prefixes, but persistence may not be expected in the face of significant 'replumbing' of the homenet. However, delegated ULA prefixes within the homenet should remain persistent through an ISP-driven renumbering event.

Provisioning such persistent prefixes may imply the need for stable storage on routing devices, and also a method for a home user to 'reset' the stored prefix should a significant reconfiguration be required (though ideally the home user should not be involved at all).

This document makes no specific recommendation towards solutions, but notes that it is very likely that all routing devices participating in a homenet must use the same internal prefix delegation method. This implies that only one delegation method should be in use.

3.4.4. Coordination of configuration information

The network elements will need to be integrated in a way that takes account of the various lifetimes on timers that are used on different elements, e.g., DHCPv6 PD, router, valid prefix and preferred prefix

timers.

3.4.5. Privacy

If ISPs offer relatively stable IPv6 prefixes to customers, the network prefix part of addresses associated with the homenet may not change over a reasonably long period of time.

The exposure of which traffic is sourced from the same homenet is thus similar to IPv4; the single IPv4 global address seen through use of IPv4 NAT gives the same hint as the global IPv6 prefix seen for IPv6 traffic.

While IPv4 NAT may obfuscate to an external observer which internal devices traffic is sourced from, IPv6, even with use of Privacy Addresses [RFC4941], adds additional exposure of which traffic is sourced from the same internal device, through use of the same IPv6 source address for a period of time.

3.5. Routing functionality

Routing functionality is required when there are multiple routers deployed within the internal home network. This functionality could be as simple as the current 'default route is up' model of IPv4 NAT, or, more likely, it would involve running an appropriate routing protocol. Regardless of the solution method, the functionality discussed below should be met.

The homenet unicast routing protocol should be based on a previously deployed protocol that has been shown to be reliable and robust, and that allows lightweight implementations. The availability of open source implementations is an important consideration. It is desirable, but not absolutely required, that the routing protocol be able to give a complete view of the network, and that it be able to pass around more than just routing information.

Multiple types of physical interfaces must be accounted for in the homenet routed topology. Technologies such as Ethernet, WiFi, Multimedia over Coax Alliance (MoCA), etc. must be capable of coexisting in the same environment and should be treated as part of any routed deployment. The inclusion of physical layer characteristics including bandwidth, loss, and latency in path computation should be considered for optimising communication in the homenet.

The routing protocol should support the generic use of multiple customer Internet connections, and the concurrent use of multiple delegated prefixes. A routing protocol that can make routing

decisions based on source and destination addresses is thus desirable, to avoid upstream ISP BCP38 ingress filtering problems. Multihoming support should also include load-balancing to multiple providers, and failover from a primary to a backup link when available. The protocol however should not require upstream ISP connectivity to be established to continue routing within the homenet.

The routing environment should be self-configuring, as discussed previously. An example of how OSPFv3 can be self-configuring in a homenet is described in [I-D.ietf-ospf-ospfv3-autoconfig]. Minimising convergence time should be a goal in any routed environment, but as a guideline a maximum convergence time at most 30 seconds should be the target (this target is somewhat arbitrary, and was chosen based on how long a typical home user might wait before attempting another reset; ideally the routers might have some status light indicating they are converging, similar to an ADSL router light indicating it is establishing a connection to its ISP).

As per prefix delegation, it is assumed that a single routing solution is in use in the homenet architecture. If there is an identified need to support multiple solutions, these must be interoperable.

An appropriate mechanism is required to discover which router(s) in the homenet are providing the CER function. Borders may include but are not limited to the interface to the upstream ISP, a gateway device to a separate home network such as a LLN network, or a gateway to a guest or private corporate extension network. In some cases there may be no border present, which may for example occur before an upstream connection has been established. The border discovery functionality may be integrated into the routing protocol itself, but may also be imported via a separate discovery mechanism.

In general, LLN or other networks should be able to attach and participate in the same way as the main homenet, or alternatively map/be gatewayed to the main homenet. Current home deployments use largely different mechanisms in sensor and basic Internet connectivity networks. IPv6 virtual machine (VM) solutions may also add additional routing requirements.

3.5.1. Multicast support

It is desirable that, subject to the capacities of devices on certain media types, multicast routing is supported across the homenet. The natural scopes for internal multicast would be link-local or site-local, with the latter constrained within the homenet, but other policy borders, e.g., to a guest subnet, or to certain media types,

may also affect where specific multicast traffic is routed.

The homenet will need to be able to automatically configure the site multicast scope and scope boundary as part of the homenet edge (border) discovery process.

There may be different drivers for multicast to be supported across the homenet, e.g., for homenet-wide service discovery should a site-scope multicast service discovery protocol be defined, or potentially for novel streaming or filesharing applications. Where multicast is routed across a homenet an appropriate multicast routing protocol is required, one that as per the unicast routing protocol should be self-configuring. It must be possible to scope or filter multicast traffic to avoid it being flooded to network media where devices cannot reasonably support it.

Multicast may also be received by or sourced from the homenet from/to external networks, e.g., where video applications use multicast to conserve the bandwidth they consume. Such multicast traffic would be greater than site scope.

The multicast environment should support the ability for applications to pick a unique multicast group to use.

3.5.2. Mobility support

Devices may be mobile within the homenet. While resident on the same subnet, their address will remain persistent, but should devices move to a different (wireless) subnet, they will acquire a new address in that subnet. It is desirable that the homenet supports internal device mobility. To do so, the homenet may either extend the reach of specific wireless subnets to enable wireless roaming across the home (availability of a specific subnet across the home), or it may support mobility protocols to facilitate such roaming where multiple subnets are used.

3.6. Security

The security of an IPv6 homenet is an important consideration. The most notable difference to the IPv4 operational model is the removal of NAT, the introduction of global addressability of devices, and thus a need to consider whether devices should have global reachability. Regardless, hosts need to be able to operate securely, end-to-end where required, and also be robust against malicious traffic directed towards them. However, there are other challenges introduced, e.g., default filtering policies at the borders between various homenet realms.

3.6.1. Addressability vs reachability

An IPv6-based home network architecture should embrace the transparent end-to-end communications model as described in [RFC2775]. Each device should be globally addressable, and those addresses must not be altered in transit. However, security perimeters can be applied to restrict end-to-end communications, and thus while a host may be globally addressable it may not be globally reachable.

[RFC4864] describes a 'Simple Security' model for IPv6 networks, whereby stateful perimeter filtering can be applied to control the reachability of devices in a homenet. RFC 4864 states in Section 4.2 that "the use of firewalls ... is recommended for those that want boundary protection in addition to host defences". It should be noted that a 'default deny' filtering approach would effectively replace the need for IPv4 NAT traversal protocols with a need to use a signalling protocol to request a firewall hole be opened, e.g., a protocol such as PCP [RFC6887]. In networks with multiple CERs, the signalling would need to handle the cases of flows that may use one or more exit routers. CERs would need to be able to advertise their existence for such protocols.

[RFC6092] expands on RFC 4864, giving a more detailed discussion of IPv6 perimeter security recommendations, without mandating a 'default deny' approach. Indeed, RFC 6092 does not enforce a particular mode of operation, instead stating that CERs must provide an easily selected configuration option that permits a 'transparent' mode, thus ensuring a 'default allow' model is available. The homenet architecture text makes no recommendation on the default setting, and refers the reader to RFC 6092.

3.6.2. Filtering at borders

It is desirable that there are mechanisms to detect different types of borders within the homenet, as discussed previously, and further mechanisms to then apply different types of filtering policies at those borders, e.g., whether naming and service discovery should pass a given border. Any such policies should be able to be easily applied by typical home users, e.g., to give a user in a guest network access to media services in the home, or access to a printer. Simple mechanisms to apply policy changes, or associations between devices, will be required.

There are cases where full internal connectivity may not be desirable, e.g., in certain utility networking scenarios, or where filtering is required for policy reasons against guest network subnet(s). Some scenarios/models may as a result involve running

isolated subnet(s) with their own CERs. In such cases connectivity would only be expected within each isolated network (though traffic may potentially pass between them via external providers).

LLNs provide an another example of where there may be secure perimeters inside the homenet. Constrained LLN nodes may implement network key security but may depend on access policies enforced by the LLN border router.

3.6.3. Partial Effectiveness of NAT and Firewalls

Security by way of obscurity (address translation) or through firewalls (filtering) is at best only partially effective. The very poor security track record of home computer, home networking and business PC computers and networking is testimony to this. A security compromise behind the firewall of any device exposes all others, making an entire network that relies on obscurity or a firewall as vulnerable as the most insecure device on the private side of the network.

However, given current evidence of home network products with very poor default device security, putting a firewall in place does provide some level of protection. The use of firewalls today, whether a good practice or not, is common practice and whatever protection afforded, even if marginally effective, should not be lost. Thus, while it is highly desirable that all hosts in a homenet be adequately protected by built-in security functions, it should also be assumed that all CERs will continue to support appropriate perimeter defence functions, as per [I-D.ietf-v6ops-6204bis].

3.6.4. Exfiltration concerns

As homenets become more complex, with more devices, and with service discovery potentially enabled across the whole home, there are potential concerns over the leakage of information should devices use discovery protocols to gather information and report it to equipment vendors or application service providers.

While it is not clear how such exfiltration could be easily avoided, the threat should be recognised, be it from a new piece of hardware or some 'app' installed on personal device.

3.6.5. Device capabilities

In terms of the devices, homenet hosts should implement their own security policies in accordance to their computing capabilities. They should have the means to request transparent communications to be able to be initiated to them through security filters in the

homenet, either for all ports or for specific services. Users should have simple methods to associate devices to services that they wish to operate transparently through (CER) borders.

3.6.6. ULAs as a hint of connection origin

As noted in Section 3.6, if appropriate filtering is in place on the CER(s), as mandated by RFC 6204 requirement S-2, a ULA source address may be taken as an indication of locally sourced traffic. This indication could then be used with security settings to designate between which nodes a particular application is allowed to communicate, provided ULA address space is filtered appropriately at the boundary of the realm.

3.7. Naming and Service Discovery

The homenet requires devices to be able to determine and use unique names by which they can be accessed on the network. Users and devices will need to be able to discover devices and services available on the network, e.g., media servers, printers, displays or specific home automation devices. Thus naming and service discovery must be supported in the homenet, and, given the nature of typical home network users, the service(s) providing this function must as far as possible support unmanaged operation.

The naming system will be required to work internally or externally, be the user within the homenet or outside it, i.e., the user should be able to refer to devices by name, and potentially connect to them, wherever they may be. The most natural way to think about such naming and service discovery is to enable it to work across the entire homenet residence (site), disregarding technical borders such as subnets but respecting policy borders such as those between guest and other internal network realms. Remote access may be desired by the homenet residents while travelling, but also potentially by manufacturers or other 'benevolent' third parties.

3.7.1. Discovering services

Users will typically perform service discovery through graphical user interfaces (GUIs) that allow them to browse services on their network in an appropriate and intuitive way. Devices may also need to discover other devices, without any user intervention or choice. Either way, such interfaces are beyond the scope of this document, but the interface should have an appropriate application programming interface (API) for the discovery to be performed.

Such interfaces may also typically hide the local domain name element from users, especially where only one name space is available.

However, as we discuss below, in some cases the ability to discover available domains may be useful.

We note that current zero-configuration service discovery protocols are generally aimed at single subnets. There is thus a choice to make for multi-subnet homenets as to whether such protocols should be proxied or extended to operate across a whole homenet. In this context, that may mean bridging a link-local method, taking care to avoid loops, or extending the scope of multicast traffic used for the purpose. It may mean that some proxy or hybrid service is utilised, perhaps co-resident on the CER. Or it may be that a new approach is preferable, e.g., flooding information around the homenet as attributes within the routing protocol (which could allow per-prefix configuration). However, we should prefer approaches that are backwardly compatible, and allow current implementations to continue to be used. Note that this document does not mandate a particular solution, rather it expresses the principles that should be used for a homenet naming and service discovery environment.

One of the primary challenges facing service discovery today is lack of interoperability due to the ever increasing number of service discovery protocols available. While it is conceivable for consumer devices to support multiple discovery protocols, this is clearly not the most efficient use of network and computational resources. One goal of the homenet architecture should be a path to service discovery protocol interoperability either through a standards based translation scheme, hooks into current protocols to allow some for of communication among discovery protocols, extensions to support a central service repository in the homenet, or simply convergence towards a unified protocol suite.

3.7.2. Assigning names to devices

Given the large number of devices that may be networked in the future, devices should have a means to generate their own unique names within a homenet, and to detect clashes should they arise, e.g., where a second device of the same type/vendor as an existing device with the same default name is deployed, or where a new subnet is added to the homenet which already has a device of the same name. It is expected that a device should have a fixed name while within the scope of the homenet.

Users will also want simple ways to (re)name devices, again most likely through an appropriate and intuitive interface that is beyond the scope of this document. Note the name a user assigns to a device may be a label that is stored on the device as an attribute of the device, and may be distinct from the name used in a name service, e.g., 'Study Laser Printer' as opposed to printer2.<somedomain>.

3.7.3. The homenet name service

The homenet name service should support both lookups and discovery. A lookup would operate via a direct query to a known service, while discovery may use multicast messages or a service where applications register in order to be found.

It is highly desirable that the homenet name service must at the very least co-exist with the Internet name service. There should also be a bias towards proven, existing solutions. The strong implication is thus that the homenet service is DNS-based, or DNS-compatible. There are naming protocols that are designed to be configured and operate Internet-wide, like unicast-based DNS, but also protocols that are designed for zero-configuration local environments, like mDNS [RFC6762].

When DNS is used as the homenet name service, it typically includes both a resolving service and an authoritative service. The authoritative service hosts the homenet related zone. One approach when provisioning such a name service, which is designed to facilitate name resolution from the global Internet, is to run an authoritative name service on the CER and a secondary authoritative name service provided by the ISP or perhaps an external third party.

Where zero configuration name services are used, it is desirable that these can also coexist with the Internet name service. In particular, where the homenet is using a global name space, it is desirable that devices have the ability, where desired, to add entries to that name space. There should also be a mechanism for such entries to be removed or expired from the global name space.

To protect against attacks such as cache poisoning, where an attacker is able to insert a bogus DNS entry in the local cache, it is desirable to support appropriate name service security methods, including DNS Security Extensions (DNSSEC) [RFC4033], on both the authoritative server and the resolver sides. Where DNS is used, the homenet router or naming service must not prevent DNSSEC from operating.

While this document does not specify hardware requirements, it is worth noting briefly here that e.g., in support of DNSSEC, appropriate homenet devices should have good random number generation capability, and future homenet specifications should indicate where high quality random number generators, i.e., with decent entropy, are needed.

Finally, the impact of a change in CER must be considered. It would be desirable to retain any relevant state (configuration) that was

held in the old CER. This might imply that state information should be distributed in the homenet, to be recoverable by/to the new CER, or to the homenet's ISP or a third party externally provided service by some means.

3.7.4. Name spaces

If access to homenet devices is required remotely from anywhere on the Internet, then at least one globally unique name space is required, though the use of multiple name spaces should not be precluded. One approach is that the name space(s) used for the homenet would be served authoritatively by the homenet, most likely by a server resident on the CER. Such name spaces may be acquired by the user or provided/generated by their ISP or an alternative externally provided service. It is likely that the default case is that a homenet will use a global domain provided by the ISP, but advanced users wishing to use a name space that is independent of their provider in the longer term should be able to acquire and use their own domain name. For users wanting to use their own independent domain names, such services are already available.

Devices may also be assigned different names in different name spaces, e.g., by third parties who may manage systems or devices in the homenet on behalf of the resident(s). Remote management of the homenet is out of scope of this document.

If however a global name space is not available, the homenet will need to pick and use a local name space which would only have meaning within the local homenet (i.e., it would not be used for remote access to the homenet). The .local name space currently has a special meaning for certain existing protocols which have link-local scope, and is thus not appropriate for multi-subnet home networks. A different name space is thus required for the homenet.

One approach for picking a local name space is to use an Ambiguous Local Qualified Domain Name (ALQDN) space, such as .sitelocal (or an appropriate name reserved for the purpose). While this is a simple approach, there is the potential in principle for devices that are bookmarked somehow by name by an application in one homenet to be confused with a device with the same name in another homenet. In practice however the underlying service discovery protocols should be capable of handling moving to a network where a new device is using the same name as a device used previously in another homenet.

An alternative approach for a local name space would be to use a Unique Locally Qualified Domain Name (ULQDN) space such as .<UniqueString>.sitelocal. The <UniqueString> could be generated in a variety of ways, one potentially being based on the local /48 ULA

prefix being used across the homenet. Such a <UniqueString> should survive a cold restart, i.e., be consistent after a network power-down, or, if a value is not set on startup, the CER or device running the name service should generate a default value. It would be desirable for the homenet user to be able to override the <UniqueString> with a value of their choice, but that would increase the likelihood of a name conflict. Any generated <UniqueString> should not be predictable; thus adding a salt/hash function would be desirable.

In the (likely) event that the homenet is accessible from outside the homenet (using the global name space), it is vital that the homenet name space follow the rules and conventions of the global name space. In this mode of operation, names in the homenet (including those automatically generated by devices) must be usable as labels in the global name space. [RFC5890] describes considerations for Internationalizing Domain Names in Applications (IDNA).

Also, with the introduction of new 'dotless' top level domains, there is also potential for ambiguity between, for example, a local host called 'computer' and (if it is registered) a .computer gTLD. Thus qualified names should always be used, whether these are exposed to the user or not. The IAB has issued a statement which explains why dotless domains should be considered harmful [IABdotless].

There may be use cases where either different name spaces may be desired for different realms in the homenet, or for segmentation of a single name space within the homenet. Thus hierarchical name space management is likely to be required. There should also be nothing to prevent individual device(s) being independently registered in external name spaces.

Where a user is in a remote network wishing to access devices in their home network, there may be a requirement to consider the domain search order presented where multiple associated name spaces exist. This also implies that a domain discovery function is desirable.

It may be the case that not all devices in the homenet are made available by name via an Internet name space, and that a 'split view' is preferred for certain devices, whereby devices inside the homenet see different DNS responses to those outside.

This document makes no assumption about the presence or omission of a reverse lookup service. There is an argument that it may be useful for presenting logging information to users with meaningful device names rather than literal addresses. There are also some services, most notably email mail exchangers, where some operators have chosen to require a valid reverse lookup before accepting connections.

3.7.5. Independent operation

Name resolution and service discovery for reachable devices must continue to function if the local network is disconnected from the global Internet, e.g., a local media server should still be available even if the Internet link is down for an extended period. This implies the local network should also be able to perform a complete restart in the absence of external connectivity, and have local naming and service discovery operate correctly.

The approach described above of a local authoritative name service with a cache would allow local operation for sustained ISP outages.

Having an independent local trust anchor is desirable, to support secure exchanges should external connectivity be unavailable.

A change in ISP should not affect local naming and service discovery. However, if the homenet uses a global name space provided by the ISP, then this will obviously have an impact if the user changes their network provider.

3.7.6. Considerations for LLNs

In some parts of the homenet, in particular LLNs or any devices where battery power is used, devices may be sleeping, in which case a proxy for such nodes may be required, that could respond (for example) to multicast service discovery requests. Those same devices or parts of the network may have less capacity for multicast traffic that may be flooded from other parts of the network. In general, message utilisation should be efficient considering the network technologies and constrained devices that the service may need to operate over.

There are efforts underway to determine naming and discovery solutions for use by the Constrained Application Protocol (CoAP) [I-D.ietf-core-coap] in LLN networks. These are outside the scope of this document.

3.7.7. DNS resolver discovery

Automatic discovery of a name service to allow client devices in the homenet to resolve external domains on the Internet is required, and such discovery must support clients that may be a number of router hops away from the name service. Similarly it may be desirable to convey any DNS domain search list that may be in effect for the homenet.

3.7.8. Devices roaming to/from the homenet

It is likely that some devices which have registered names within the homenet Internet name space and that are mobile will attach to the Internet at other locations and acquire an IP address at those locations. Devices may move between different homenets. In such cases it is desirable that devices may be accessed by the same name as is used in their home network.

Solutions to this problem are not discussed in this document. They may include use of Mobile IPv6 or Dynamic DNS, either of which would put additional requirements on to the homenet, or establishment of a (VPN) tunnel to a server in the home network.

3.8. Other Considerations

This section discusses two other considerations for home networking that the architecture should not preclude, but that this text is neutral towards.

3.8.1. Quality of Service

Support for Quality of Service in a multi-service homenet may be a requirement, e.g., for a critical system (perhaps healthcare related), or for differentiation between different types of traffic (file sharing, cloud storage, live streaming, VoIP, etc). Different media types may have different such properties or capabilities.

However, homenet scenarios should require no new Quality of Service protocols. A DiffServ [RFC2475] approach with a small number of predefined traffic classes may generally be sufficient, though at present there is little experience of Quality of Service deployment in home networks. It is likely that QoS, or traffic prioritisation, methods will be required at the CER, and potentially around boundaries between different media types (where for example some traffic may simply not be appropriate for some media, and need to be dropped to avoid overloading the constrained media).

There may also be complementary mechanisms that could be beneficial to application performance and behaviour in the homenet domain, such as ensuring proper buffering algorithms are used as described in [Gettys11].

3.8.2. Operations and Management

The homenet should be self-organising and configuring as far as possible, and thus should not need to be pro-actively managed by the home user. Thus specific protocols to manage the network are not

discussed in this document.

There may be some configuration parameters which are exposed to users, e.g., SSID name(s), or wireless security key(s). Users may also be expected to be aware of the functions of certain devices they connect, e.g., which are providing a server function, though service discovery protocols should make their selection as intuitive as possible.

As discussed in Section 3.6.1 the default setting on the homenet-ISP border for inbound traffic may be default deny, default allow, or some position inbetween. Whatever the default position, it should be possible for the user to change the setting.

Users may also be interested in the status of their networks and devices on the network, in which case simplified monitoring mechanisms may be desirable. It may also be the case that an ISP, or a third party, might offer management of the homenet on behalf of a user, in which case management protocols would be required. How such management is done is out of scope of this document; many solutions exist.

It is expected that network management functions would be available over IPv6 transport, even where the homenet is dual-stack.

3.9. Implementing the Architecture on IPv6

This architecture text encourages re-use of existing protocols. Thus the necessary mechanisms are largely already part of the IPv6 protocol set and common implementations, though there are some exceptions.

For automatic routing, it is expected that solutions can be found based on existing protocols. Some relatively smaller updates are likely to be required, e.g., a new mechanism may be needed in order to turn a selected protocol on by default, a mechanism may be required to automatically assign prefixes to links within the homenet.

Some functionality, if required by the architecture, may need more significant changes or require development of new protocols, e.g., support for multihoming with multiple exit routers would likely require extensions to support source and destination address based routing within the homenet.

Some protocol changes are however required in the architecture, e.g., for name resolution and service discovery, extensions to existing zero configuration link-local name resolution protocols are needed to

enable them to work across subnets, within the scope of the home network site.

Some of the hardest problems in developing solutions for home networking IPv6 architectures include discovering the right borders where the 'home' domain ends and the service provider domain begins, deciding whether some of the necessary discovery mechanism extensions should affect only the network infrastructure or also hosts, and the ability to turn on routing, prefix delegation and other functions in a backwards compatible manner.

4. Conclusions

This text defines principles and requirements for a homenet architecture. The principles and requirements documented here should be observed by any future texts describing homenet protocols for routing, prefix management, security, naming or service discovery.

5. Security Considerations

Security considerations for the homenet architecture are discussed in Section 3.6 above.

6. IANA Considerations

This document has no actions for IANA.

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Appendix A. Acknowledgments

The authors would like to thank Aamer Akhter, Mikael Abrahamsson, Mark Andrews, Dmitry Anipko, Ran Atkinson, Fred Baker, Ray Bellis, Teco Boot, John Brzozowski, Cameron Byrne, Brian Carpenter, Stuart Cheshire, Julius Chroboczek, Lorenzo Colitti, Robert Cragie, Elwyn Davies, Ralph Droms, Lars Eggert, Jim Gettys, Olafur Gudmundsson, Wassim Haddad, Joel M. Halpern, David Harrington, Lee Howard, Ray Hunter, Joel Jaeggli, Heather Kirksey, Ted Lemon, Acee Lindem, Kerry Lynn, Daniel Migault, Erik Nordmark, Michael Richardson, Mattia

Rossi, Barbara Stark, Markus Stenberg, Sander Steffann, Don Sturek, Andrew Sullivan, Dave Taht, Dave Thaler, Michael Thomas, Mark Townsley, JP Vasseur, Curtis Villamizar, Dan Wing, Russ White, and James Woodyatt for their comments and contributions within homenet WG meetings and on the WG mailing list. An acknowledgement generally means that person's text made it in to the document, or was helpful in clarifying or reinforcing an aspect of the document. It does not imply that each controbutor agrees with every point in the document.

Appendix B. Changes

This section will be removed in the final version of the text.

B.1. Version 11 (after IESG review)

Changes made include:

- Jouni Korhonen's OPSDIR review comments addressed.
- Elwyn Davies' gen-art review comments addressed.

B.2. Version 10 (after AD review)

Changes made include:

- Minor changes/clarifications resulting from AD review

B.3. Version 09 (after WGLC)

Changes made include:

- Added note about multicast into or out of site
- Removed further personal draft references, replaced with covering text
- Routing functionality text updated to avoid ambiguity
- Added note that devices away from homenet may tunnel home (via VPN)
- Added note that homenets more exposed to provider renumbering than with IPv4 and NAT
- Added note about devices that may be ULA-only until configured to be globally addressable

- Removed paragraph about broken CERs that do not work with prefixes other than /64
- Noted no recommendation on methods to convey prefix information is made in this text
- Stated that this text does not recommend how to form largest possible subnets
- Added text about homenet evolution and handling disparate media types
- Rephrased NAT/firewall text on marginal effectiveness
- Emphasised that multihoming may be to any number of ISPs

B.4. Version 08

Changes made include:

- Various clarifications made in response to list comments
- Added note on ULAs with IPv4, where no GUAs in use
- Added note on naming and internationalisation (IDNA)
- Added note on trust relationships when adding devices
- Added note for MPTCP
- Added various naming and SD notes
- Added various notes on delegated ISP prefixes

B.5. Version 07

Changes made include:

- Removed reference to NPTv6 in section 3.2.4. Instead now say it has an architectural cost to use in the earlier section, and thus it is not recommended for use in the homenet architecture.
- Removed 'proxy or extend?' section. Included shorter text in main body, without mandating either approach for service discovery.
- Made it clearer that ULAs are expected to be used alongside globals.

- Removed reference to 'advanced security' as described in draft-vyncke-advanced-ipv6-security.
- Balanced the text between ULQDN and ALQDN.
- Clarify text does not assume default deny or allow on CER, but that either mode may be enabled.
- Removed ULA-C reference for 'simple' addresses. Instead only suggested service discovery to find such devices.
- Reiterated that single/multiple CER models to be supported for multihoming.
- Reordered section 3.3 to improve flow.
- Added recommendation that homenet is not allocated less than /60, and a /56 is preferable.
- Tidied up first few intro sections.
- Other minor edits from list feedback.

B.6. Version 06

Changes made include:

- Stated that unmanaged goal is 'as far as possible'.
- Added note about multiple /48 ULAs potentially being in use.
- Minor edits from list feedback.

B.7. Version 05

Changes made include:

- Some significant changes to naming and SD section.
- Removed some expired drafts.
- Added notes about issues caused by ISP only delegating a /64.
- Recommended against using prefixes longer than /64.
- Suggested CER asks for /48 by DHCP PD, even if it only receives less.

- Added note about DS-Lite but emphasised transition is out of scope.
- Added text about multicast routing.

B.8. Version 04

Changes made include:

- Moved border section from IPv6 differences to principles section.
- Restructured principles into areas.
- Added summary of naming and service discovery discussion from WG list.

B.9. Version 03

Changes made include:

- Various improvements to the readability.
- Removed bullet lists of requirements, as requested by chair.
- Noted 6204bis has replaced advanced-cpe draft.
- Clarified the topology examples are just that.
- Emphasised we are not targetting walled gardens, but they should not be precluded.
- Also changed text about requiring support for walled gardens.
- Noted that avoiding falling foul of ingress filtering when multihomed is desirable.
- Improved text about realms, detecting borders and policies at borders.
- Stated this text makes no recommendation about default security model.
- Added some text about failure modes for users plugging things arbitrarily.
- Expanded naming and service discovery text.

- Added more text about ULAs.
- Removed reference to version 1 on chair feedback.
- Stated that NPTv6 adds architectural cost but is not a homenet matter if deployed at the CER. This text only considers the internal homenet.
- Noted multihoming is supported.
- Noted routers may not by separate devices, they may be embedded in devices.
- Clarified simple and advanced security some more, and RFC 4864 and 6092.
- Stated that there should be just one secret key, if any are used at all.
- For multihoming, support multiple CERs but note that routing to the correct CER to avoid ISP filtering may not be optimal within the homenet.
- Added some ISPs renumber due to privacy laws.
- Removed extra repeated references to Simple Security.
- Removed some solution creep on RIOs/RAs.
- Load-balancing scenario added as to be supported.

B.10. Version 02

Changes made include:

- Made the IPv6 implications section briefer.
- Changed Network Models section to describe properties of the homenet with illustrative examples, rather than implying the number of models was fixed to the six shown in 01.
- Text to state multihoming support focused on single CER model. Multiple CER support is desirable, but not required.
- Stated that NPTv6 not supported.
- Added considerations section for operations and management.

- Added bullet point principles/requirements to Section 3.4.
- Changed IPv6 solutions must not adversely affect IPv4 to should not.
- End-to-end section expanded to talk about "Simple Security" and borders.
- Extended text on naming and service discovery.
- Added reference to RFC 2775, RFC 6177.
- Added reference to the new xmDNS draft.
- Added naming/SD requirements from Ralph Droms.

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