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Mapping of Address and Port with Encapsulation (MAP) draft-ietf-softwire-map-06

Abstract

This document describes a mechanism for transporting IPv4 packets across an IPv6 network using IP encapsulation, and a generic mechanism for mapping between IPv6 addresses and IPv4 addresses and transport layer ports.

Status of This Memo

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Table of Contents

1. Introduction

Mapping of IPv4 addresses in IPv6 addresses has been described in numerous mechanisms dating back to 1996 [RFC1933]. The Automatic tunneling mechanism described in RFC1933, assigned a globally unique IPv6 address to a host by combining the host's IPv4 address with a well-known IPv6 prefix. Given an IPv6 packet with a destination address with an embedded IPv4 address, a node could automatically tunnel this packet by extracting the IPv4 tunnel end-point address from the IPv6 destination address.

There are numerous variations of this idea, described in 6over4 [RFC2529], 6to4 [RFC3056], ISATAP [RFC5214], and 6rd [RFC5969].

The commonalities of all these IPv6 over IPv4 mechanisms are:

- Automatically provisions an IPv6 address for a host or an IPv6 prefix for a site

- Algorithmic or implicit address resolution of tunnel end point addresses. Given an IPv6 destination address, an IPv4 tunnel endpoint address can be calculated.

- Embedding of an IPv4 address or part thereof into an IPv6 address.

In phases of IPv4 to IPv6 migration, IPv6 only networks will be common, while there will still be a need for residual IPv4 deployment. This document describes a generic mapping of IPv4 to IPv6, and a mechanism for encapsulating IPv4 over IPv6.

Just as the IPv6 over IPv4 mechanisms referred to above, the residual IPv4 over IPv6 mechanism must be capable of:

- Provisioning an IPv4 prefix, an IPv4 address or a shared IPv4 address.

- Algorithmically map between an IPv4 prefix, IPv4 address or a shared IPv4 address and an IPv6 address.

The mapping scheme described here supports encapsulation of IPv4 packets in IPv6 in both mesh and hub and spoke topologies, including address mappings with full independence between IPv6 and IPv4 addresses.

This document describes delivery of IPv4 unicast service across an IPv6 infrastructure. IPv4 multicast is not considered further in this document.

The A+P (Address and Port) architecture of sharing an IPv4 address by distributing the port space is described in [RFC6346]. Specifically section 4 of [RFC6346] covers stateless mapping. The corresponding

stateful solution DS-lite is described in [RFC6333]. The motivation for the work is described in [I-D.ietf-softwire-stateless-4v6-motivation].

A companion document defines a DHCPv6 option for provisioning of MAP [I-D.ietf-softwire-map-dhcp]. Other means of provisioning is possible. Deployment considerations are described in [I-D.mdt-softwire-map-deployment].

MAP relies on IPv6 and is designed to deliver production-quality dual-stack service while allowing IPv4 to be phased out within the SP network. The phasing out of IPv4 within the SP network is independent of whether the end user disables IPv4 service or not. Further, "Greenfield"; IPv6-only networks may use MAP in order to deliver IPv4 to sites via the IPv6 network.

2. Conventions

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

3. Terminology

MAP domain:	One or more MAP CEs and BRs connected to the same virtual link. A service provider may deploy a single MAP domain, or may utilize multiple MAP domains.
MAP Rule	A set of parameters describing the mapping between an IPv4 prefix, IPv4 address or shared IPv4 address and an IPv6 prefix or address. Each domain uses a different mapping rule set.
MAP node	A device that implements MAP.
MAP Border Relay (BR):	A MAP enabled router managed by the service provider at the edge of a MAP domain. A Border Relay router has at least an IPv6-enabled interface and an IPv4 interface connected to the native IPv4 network. A MAP BR may also be referred to simply as a "BR" within the context of MAP.
MAP Customer Edge (CE):	A device functioning as a Customer Edge router in a MAP deployment. A typical MAP CE adopting MAP rules will serve a residential site with one WAN side interface, and one or more LAN side interfaces. A MAP CE may also be referred to simply as a "CE" within the context of MAP.

Port-set: The separate part of the transport layer port

space; denoted as a port-set.

Port-set ID (PSID): Algorithmically identifies a set of ports exclusively assigned to a CE.

Shared IPv4 address: An IPv4 address that is shared among multiple CEs. Only ports that belong to the assigned port-set can be used for communication. Also known as a Port-Restricted IPv4 address.

End-user IPv6 prefix: The IPv6 prefix assigned to an End-user CE by other means than MAP itself. E.g. Provisioned using DHCPv6 PD [RFC3633], assigned via SLAAC [RFC4862], or configured manually. It is unique for each CE.

MAP IPv6 address: The IPv6 address used to reach the MAP function of a CE from other CEs and from BRs.

Rule IPv6 prefix: An IPv6 prefix assigned by a Service Provider for a mapping rule.

Rule IPv4 prefix: An IPv4 prefix assigned by a Service Provider for a mapping rule.

Embedded Address (EA) bits: The IPv4 EA-bits in the IPv6 address identify an IPv4 prefix/address (or part thereof) or a shared IPv4 address (or part thereof) and a port-set identifier.

4. Architecture

In accordance with the requirements stated above, the MAP mechanism can operate with shared IPv4 addresses, full IPv4 addresses or IPv4 prefixes. Operation with shared IPv4 addresses is described here, and the differences for full IPv4 addresses and prefixes are described below.

The MAP mechanism uses existing standard building blocks. The existing NAPT on the CE is used with additional support for restricting transport protocol ports, ICMP identifiers and fragment identifiers to the configured port set. For packets outbound from the private IPv4 network, the CE NAPT MUST translate transport identifiers (e.g. TCP and UDP port numbers) so that they fall within the CE's assigned port-range.

The NAPT MUST in turn be connected to a MAP aware forwarding function, that does encapsulation/ decapsulation of IPv4 packets in IPv6. MAP supports the encapsulation mode specified in [RFC2473]. In addition MAP specifies an algorithm to do "address resolution"

from an IPv4 address and port to an IPv6 address. This algorithmic mapping is specified in Section 5.

The MAP architecture described here, restricts the use of the shared IPv4 address to only be used as the global address (outside) of the NAPT [RFC2663] running on the CE. A shared IPv4 address MUST NOT be used to identify an interface. While it is theoretically possible to make host stacks and applications port-aware, that is considered too drastic a change to the IP model [RFC6250].

For full IPv4 addresses and IPv4 prefixes, the architecture just described applies with two differences. First, a full IPv4 address or IPv4 prefix can be used as it is today, e.g., for identifying an interface or as a DHCP pool, respectively. Secondly, the NAPT is not required to restrict the ports used on outgoing packets.

This architecture is illustrated in Figure 1.

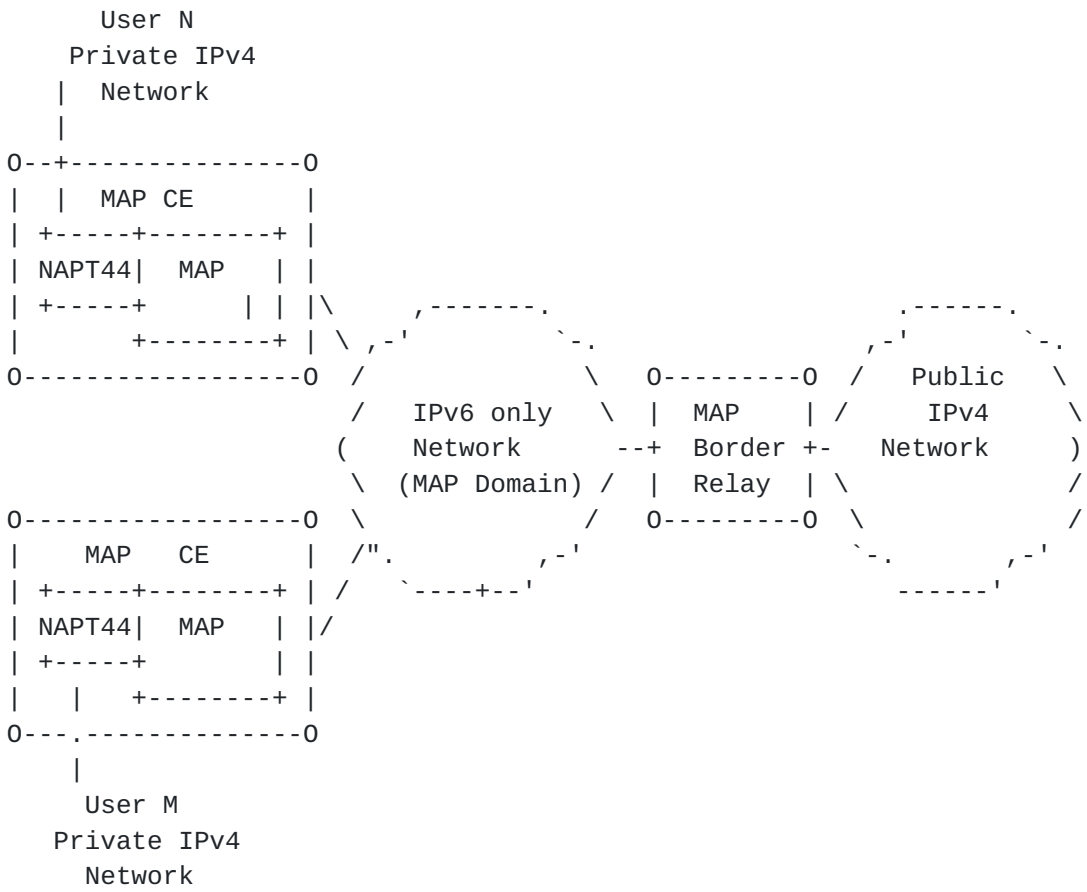


Figure 1: Network Topology

The MAP BR is responsible for connecting external IPv4 networks to the IPv4 nodes in one or more MAP domains.

5. Mapping Algorithm

A MAP node is provisioned with one or more mapping rules.

Mapping rules are used differently depending on their function. Every MAP node must be provisioned with a Basic mapping rule. This is used by the node to configure its IPv4 address, IPv4 prefix or shared IPv4 address. This same basic rule can also be used for forwarding, where an IPv4 destination address and optionally a destination port is mapped into an IPv6 address. Additional mapping rules are specified to allow for multiple different IPv4 sub-nets to exist within the domain and optimize forwarding between them.

Traffic outside of the domain (i.e. When the destination IPv4 address does not match (using longest matching prefix) any Rule IPv4 prefix in the Rules database) is forwarded to the BR.

There are two types of mapping rules:

1. Basic Mapping Rule (BMR) - mandatory. A CE can be provisioned with multiple End-user IPv6 prefixes. There can only be one Basic Mapping Rule per End-user IPv6 prefix. However all CE's having End-user IPv6 prefixes within (aggregated by) the same Rule IPv6 prefix may share the same Basic Mapping Rule. In combination with the End-user IPv6 prefix, the Basic Mapping Rule is used to derive the IPv4 prefix, address, or shared address and the PSID assigned to the CE.

2. Forwarding Mapping Rule (FMR) - optional, used for forwarding. The Basic Mapping Rule is also a Forwarding Mapping Rule. Each Forwarding Mapping Rule will result in an entry in the Rules table for the Rule IPv4 prefix. Given a destination IPv4 address and port within the MAP domain, a MAP node can use the matching FMR to derive the End-user IPv6 address of the interface through which that IPv4 destination address and port combination can be reached.

Both mapping rules share the same parameters:

- Rule IPv6 prefix (including prefix length)

- Rule IPv4 prefix (including prefix length)

- Rule EA-bits length (in bits)

A MAP node finds its Basic Mapping Rule by doing a longest match between the End-user IPv6 prefix and the Rule IPv6 prefix in the Mapping Rules table. The rule is then used for IPv4 prefix, address or shared address assignment.

A MAP IPv6 address is formed from the BMR Rule IPv6 prefix. This address MUST be assigned to an interface of the MAP node and is used to terminate all MAP traffic being sent or received to the node.

Port-aware IPv4 entries in the Rules table are installed for all the Forwarding Mapping Rules and an default route to the MAP BR (see section Section 5.4.

Forwarding rules are used to allow direct communication between MAP CEs, known as mesh mode. In hub and spoke mode, there are no forwarding rules, all traffic MUST be forwarded directly to the BR.

5.1. Port mapping algorithm

The port mapping algorithm is used in domains whose rules allow IPv4 address sharing.

The simplest way to represent a port range is using a notation similar to CIDR [RFC4632]. For example the first 256 ports are represented as port prefix 0.0/8. The last 256 ports as 255.0/8. In hexadecimal, 0x0000/8 (PSID = 0) and 0xFF00/8 (PSID = 0xFF). Using this technique, but wishing to avoid allocating the system ports [I-D .ietf-tsvwg-iana-ports] to the user, one would have to exclude the use of one or more PSIDs (e.g., PSIDs 0 to 3 in the example just given).

As will be seen shortly, the PSID forms a portion of the End-user IPv6 prefix. To minimise dependencies between the End-user IPv6 prefix and the assigned port set, it is desirable to minimize the restrictions on the possible PSID values. This is achieved by using an infix representation of the port value. Using such a representation, the well-known ports are excluded by restrictions on the value of the first bit field (A) rather than the PSID.

The infix algorithm allocates ports to a given CE as a series of contiguous ranges spaced at regular intervals throughout the complete range of possible port set values.

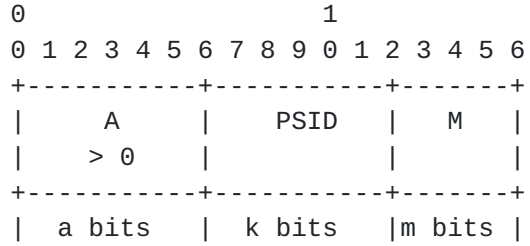


Figure 2: Structure of a port-restricted port field

a-bits The number of offset bits. The default Offset bits (a) are 6,

this excludes the system ports (0-1023).

A Selects the range of the port number. For a > 0, A MUST be larger than 0. This ensures that the algorithm excludes the system ports. For this value of a, the system ports, but no others, are excluded by requiring that A be greater than 0. For smaller values of a, A still has to be greater than 0, but this excludes ports above 1023. For larger values of a, the minimum value of A has to be higher to exclude all the system ports. The interval between successive contiguous ranges assigned to the same user is 2^a.

PSID The Port Set Identifier. Different Port-Set Identifiers (PSID) guarantee non-overlapping port-sets.

k-bits The length in bits of the PSID field. The sharing ratio is 2^k. The number of ports assigned to the user is 2^(16-k) - 2^m (excluded ports)

M Selects the specific port within the particular range specified by the concatenation of A and the PSID.

m bits The size contiguous ports. The number of contiguous ports is given by 2^m.

5.2. Basic mapping rule (BMR)

The Basic Mapping Rule is mandatory, used by the CE to provision itself with an IPv4 prefix, IPv4 address or shared IPv4 address. Recall from Section 5 that the BMR consists of the following parameters:

o Rule IPv6 prefix (including prefix length)

o Rule IPv4 prefix (including prefix length)

o Rule EA-bits length (in bits)

Figure 3 shows the structure of the complete MAP IPv6 address as specified in this document.

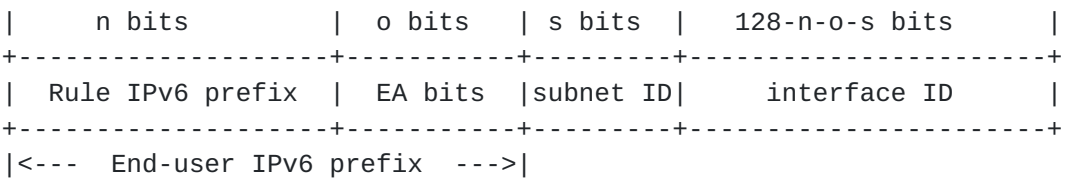


Figure 3: MAP IPv6 Address Format

The Rule IPv6 prefix is the part of the End-user IPv6 prefix that is common among all CEs using the same Basic Mapping Rule within the MAP domain. The EA bits encode the CE specific IPv4 address and port information. The EA bits, which are unique for a given Rule IPv6 prefix, can contain a full or part of an IPv4 address and, in the shared IPv4 address case, a Port-Set Identifier (PSID). An EA-bit length of 0 signifies that all relevant MAP IPv4 addressing information is passed directly in the BMR, and not derived from the End-user IPv6 prefix.

The MAP IPv6 address is created by concatenating the End-user IPv6 prefix with the MAP subnet identifier (if the End-user IPv6 prefix is shorter than 64 bits) and the interface identifier as specified in Section 6.

The MAP subnet identifier is defined to be the first subnet (all bits set to zero).

Define:

r = length of the IPv4 prefix given by the BMR;

o = length of the EA bit field as given by the BMR;

p = length of the IPv4 suffix contained in the EA bit field.

The length r MAY be zero, in which case the complete IPv4 address or prefix is encoded in the EA bits. If only a part of the IPv4 address /prefix is encoded in the EA bits, the Rule IPv4 prefix is provisioned to the CE by other means (e.g. a DHCPv6 option). To create a complete IPv4 address (or prefix), the IPv4 address suffix (p) from the EA bits, is concatenated with the Rule IPv4 prefix (r bits).

The offset of the EA bits field in the IPv6 address is equal to the

BMR Rule IPv6 prefix length. The length of the EA bits field (o) is given by the BMR Rule EA-bits length, and can be between 0 and 48. A length of 48 means that the complete IPv4 address and port is embedded in the End-user IPv6 prefix (a single port is assigned). A length of 0 means that no part of the IPv4 address or port is embedded in the address. The sum of the Rule IPv6 Prefix length and the Rule EA-bits length MUST be less or equal than the End-user IPv6 prefix length.

If o + r < 32 (length of the IPv4 address in bits), then an IPv4 prefix is assigned. This case is shown in Figure 4.

IPv4 prefix:

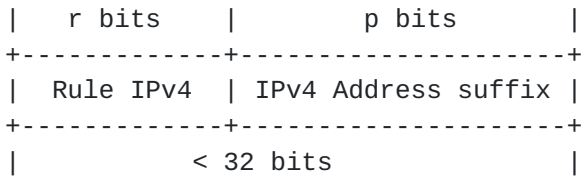


Figure 4: IPv4 prefix

If o + r is equal to 32, then a full IPv4 address is to be assigned. The address is created by concatenating the Rule IPv4 prefix and the EA-bits. This case is shown in Figure 5.

Complete IPv4 address:

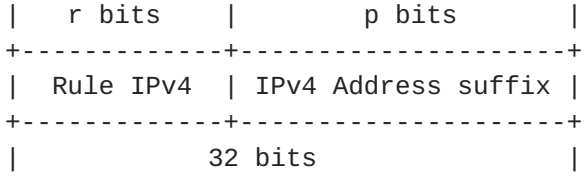
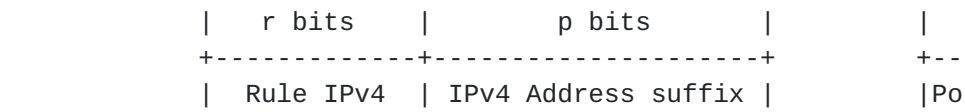


Figure 5: Complete IPv4 address

If o + r is > 32, then a shared IPv4 address is to be assigned. The number of IPv4 address suffix bits (p) in the EA bits is given by 32 - r bits. The PSID bits are used to create a port-set. The length of the PSID bit field within EA bits is: q = o - p.

Shared IPv4 address:



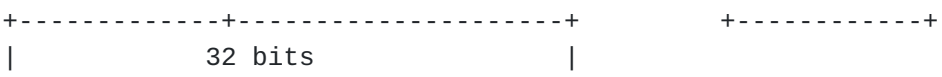

32 bits

Figure 6: Shared IPv4 address

The length of r MAY be 32, with no part of the IPv4 address embedded in the EA bits. This results in a mapping with no dependence between the IPv4 address and the IPv6 address. In addition the length of o MAY be zero (no EA bits embedded in the End-User IPv6 prefix), meaning that also the PSID is provisioned using e.g. the DHCP option.

See Appendix A for an example of the Basic Mapping Rule.

5.3. Forwarding mapping rule (FMR)

The Forwarding Mapping Rule is optional, and used in mesh mode to merit direct CE to CE connectivity.

On adding an FMR rule, an IPv4 route is installed in the Rules table for the Rule IPv4 prefix.

On forwarding an IPv4 packet, a best matching prefix look up is done in the Rules table and the correct FMR is chosen.

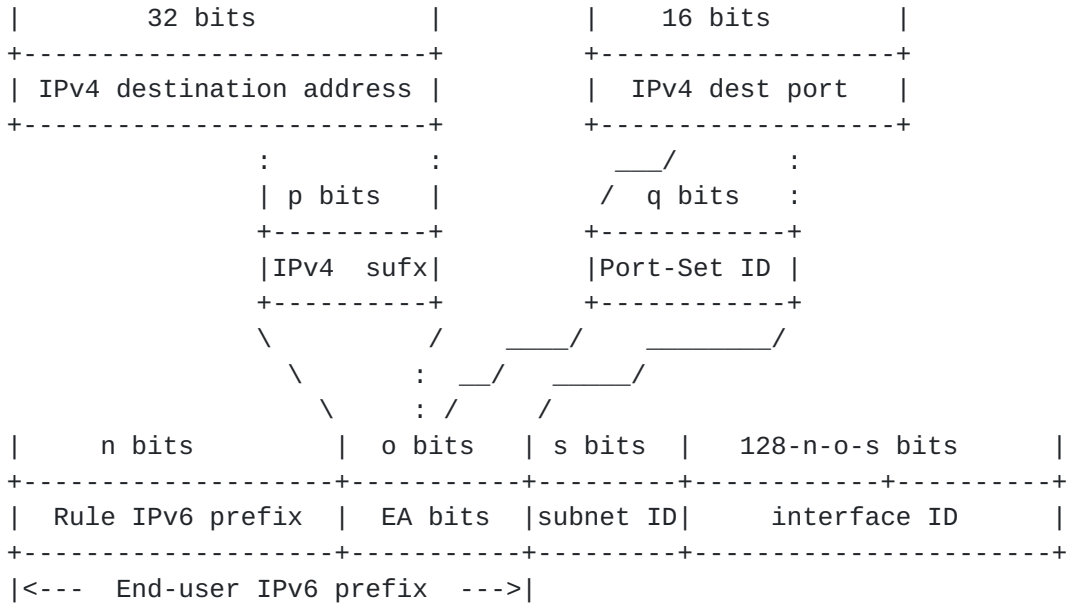


Figure 7: Deriving of MAP IPv6 address

See Appendix A for an example of the Forwarding Mapping Rule.

5.4. Destinations outside the MAP domain

IPv4 traffic between MAP nodes that are all within one MAP domain is encapsulated in IPv6, with the senders MAP IPv6 address as the IPv6 source address and the receiving MAP node's MAP IPv6 address as the IPv6 destination address. To reach IPv4 destinations outside of the MAP domain, traffic is also encapsulated in IPv6, but the destination IPv6 address is set to the configured IPv6 address of the MAP BR.

On the CE, the path to the BR can be represented as a point to point IPv4 over IPv6 tunnel [RFC2473] with the source address of the tunnel being the CE's MAP IPv6 address and the BR IPv6 address as the remote tunnel address. When MAP is enabled, a typical CE router will install a default route to the BR.

The BR forwards traffic received from the outside to CE's using the normal MAP forwarding rules.

6. The IPv6 Interface Identifier

The Interface identifier format of a MAP node is described below.

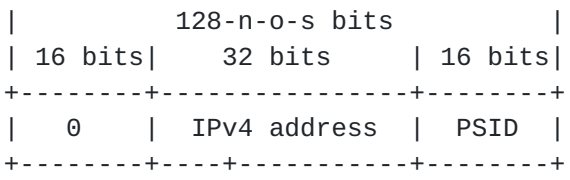


Figure 8

In the case of an IPv4 prefix, the IPv4 address field is right-padded with zeroes up to 32 bits. The PSID field is left-padded to create a 16 bit field. For an IPv4 prefix or a complete IPv4 address, the PSID field is zero.

If the End-user IPv6 prefix length is larger than 64, the most significant parts of the interface identifier is overwritten by the prefix.

7. MAP Configuration

For a given MAP domain, the BR and CE MUST be configured with the following MAP elements. The configured values for these elements are identical for all CEs and BRs within a given MAP domain.

- The Basic Mapping Rule and optionally the Forwarding Mapping Rules, including the Rule IPv6 prefix, Rule IPv4 prefix, and Length of EA bits

- Hub and spoke mode or Mesh mode. (If all traffic should be sent to the BR, or if direct CE to CE traffic should be supported).

In addition the MAP CE MUST be configured with the IPv6 address(es) of the MAP BR (Section 5.4).

7.1. MAP CE

The MAP elements are set to values that are the same across all CEs within a MAP domain. The values may be configured in a variety of manners, including provisioning methods such as the Broadband Forum's "TR-69" Residential Gateway management interface, an XML-based object retrieved after IPv6 connectivity is established, or manual configuration by an administrator. This document describes how to configure the necessary parameters via a single IPv6 DHCP option. A CE that allows IPv6 configuration by DHCP SHOULD implement this option. Other configuration and management methods may use the format described by this option for consistency and convenience of implementation on CEs that support multiple configuration methods.

The only remaining provisioning information the CE requires in order to calculate the MAP IPv4 address and enable IPv4 connectivity is the IPv6 prefix for the CE. The End-user IPv6 prefix is configured as part of obtaining IPv6 Internet access.

A single MAP CE MAY be connected to more than one MAP domain, just as any router may have more than one IPv4-enabled service provider facing interface and more than one set of associated addresses assigned by DHCP. Each domain a given CE operates within would require its own set of MAP configuration elements and would generate its own IPv4 address.

The MAP DHCP option is specified in [I-D.ietf-softwire-map-dhcp].

7.2. MAP BR

The MAP BR MUST be configured with the same MAP elements as the MAP CEs operating within the same domain.

For increased reliability and load balancing, the BR IPv6 address MAY be an anycast address shared across a given MAP domain. As MAP is stateless, any BR may be used at any time. If the BR IPv6 address is anycast the relay MUST use this anycast IPv6 address as the source address in packets relayed to CEs.

Since MAP uses provider address space, no specific routes need to be advertised externally for MAP to operate, neither in IPv6 nor IPv4 BGP. However, if anycast is used for the MAP IPv6 relays, the anycast addresses must be advertised in the service provider's IGP.

7.3. Backwards compatibility

A MAP-E CE provisioned with only the IPv6 address of the BR, and with no IPv4 address and port range configured by other means, MUST disable its NAT44 functionality. This characteristic makes a MAP CE compatible with DS-Lite [RFC6333] AFTRs, whose addresses are configured as the MAP BR.

8. Forwarding Considerations

Figure 1 depicts the overall MAP architecture with IPv4 users (N and M) networks connected to a routed IPv6 network.

MAP supports Encapsulation mode as specified in [RFC2473].

For a shared IPv4 address, a MAP CE forwarding IPv4 packets from the LAN performs NAT44 functions first and creates appropriate NAT44 bindings. The resulting IPv4 packets MUST contain the source IPv4 address and source transport identifiers defined by MAP. The IPv4 packet is forwarded using the CE's MAP forwarding function. The IPv6 source and destination addresses MUST then be derived as per Section 5 of this draft.

8.1. Receiving Rules

A MAP CE receiving an IPv6 packet to its MAP IPv6 address sends this packet to the CE's MAP function where it is decapsulated. All other IPv6 traffic is forwarded as per the CE's IPv6 routing rules. The resulting IPv4 packet is then forwarded to the CE's NAT44 function where the destination port number MUST be checked against the stateful port mapping session table and the destination port number MUST be mapped to its original value.

A MAP BR receiving IPv6 packets selects a best matching MAP domain rule based on a longest address match of the packets' source address against the BR's configured MAP BMR prefix(es), as well as a match of the packet destination address against the configured BR IPv6 address or FMR prefix(es). The selected MAP rule allows the BR to determine the EA-bits from the source IPv6 address. The BR MUST perform a validation of the consistency of the source IPv6 address and source port number for the packet using BMR. If the packets source port number is found to be outside the range allowed for this CE and the BMR, the BR MUST drop the packet and respond with an ICMPv6 "Destination Unreachable, Source address failed ingress/egress policy" (Type 1, Code 5).

In order to prevent spoofing of IPv4 addresses, the MAP node MUST validate the embedded IPv4 source address of the encapsulated IPv6

packet with the IPv4 source address it is encapsulated by according to the parameters of the matching mapping rule. If the two source addresses do not match, the packet MUST be dropped and a counter incremented to indicate that a potential spoofing attack may be underway. Additionally, a CE MUST allow forwarding of packets sourced by the configured BR IPv6 address.

By default, the CE router MUST drop packets received on the MAP virtual interface (i.e., after decapsulation of IPv6) for IPv4 destinations not for its own IPv4 shared address, full IPv4 address or IPv4 prefix.

8.2. ICMP

ICMP message should be supported in MAP domain. Hence, the NAT44 in MAP CE must implement the behavior for ICMP message conforming to the best current practice documented in [RFC5508].

If a MAP CE receives an ICMP message having ICMP identifier field in ICMP header, NAT44 in the MAP CE must rewrite this field to a specific value assigned from the port-set. BR and other CEs must handle this field similar to the port number in the TCP/UDP header upon receiving the ICMP message with ICMP identifier field.

If a MAP node receives an ICMP error message without the ICMP identifier field for errors that is detected inside a IPv6 tunnel, a node should relay the ICMP error message to the original source. This behavior should be implemented conforming to the section 8 of [RFC2473].

8.3. Fragmentation and Path MTU Discovery

Due to the different sizes of the IPv4 and IPv6 header, handling the maximum packet size is relevant for the operation of any system connecting the two address families. There are three mechanisms to handle this issue: Path MTU discovery (PMTUD), fragmentation, and transport-layer negotiation such as the TCP Maximum Segment Size (MSS) option [RFC0897]. MAP uses all three mechanisms to deal with different cases.

8.3.1. Fragmentation in the MAP domain

Encapsulating an IPv4 packet to carry it across the MAP domain will increase its size (40 bytes). It is strongly recommended that the MTU in the MAP domain is well managed and that the IPv6 MTU on the CE WAN side interface is set so that no fragmentation occurs within the boundary of the MAP domain.

Fragmentation on MAP domain entry is described in section 7.2 of [RFC2473]

The use of an anycast source address could lead to any ICMP error message generated on the path being sent to a different BR. Therefore, using dynamic tunnel MTU Section 6.7 of [RFC2473] is subject to IPv6 Path MTU black-holes. A MAP BR SHOULD NOT by default use Path MTU discovery across the MAP domain.

Multiple BRs using the same anycast source address could send fragmented packets to the same CE at the same time. If the fragmented packets from different BRs happen to use the same fragment ID, incorrect reassembly might occur. See [RFC4459] for an analysis of the problem. Section 3.4 suggests solving the problem by fragmenting the inner packet.

8.3.2. Receiving IPv4 Fragments on the MAP domain borders

Forwarding of an IPv4 packet received from the outside of the MAP domain requires the IPv4 destination address and the transport protocol destination port. The transport protocol information is only available in the first fragment received. As described in section 5.3.3 of [RFC6346] a MAP node receiving an IPv4 fragmented packet from outside has to reassemble the packet before sending the packet onto the MAP link. If the first packet received contains the transport protocol information, it is possible to optimize this behavior by using a cache and forwarding the fragments unchanged. A description of this algorithm is outside the scope of this document.

8.3.3. Sending IPv4 fragments to the outside

If two IPv4 host behind two different MAP CE's with the same IPv4 address sends fragments to an IPv4 destination host outside the domain. Those hosts may use the same IPv4 fragmentation identifier,

resulting in incorrect reassembly of the fragments at the destination host. Given that the IPv4 fragmentation identifier is a 16 bit field, it could be used similarly to port ranges. A MAP CE SHOULD rewrite the IPv4 fragmentation identifier to be within its allocated port set.

9. NAT44 Considerations

The NAT44 implemented in the MAP CE SHOULD conform with the behavior and best current practice documented in [RFC4787], [RFC5508], and [RFC5382]. In MAP address sharing mode (determined by the MAP domain /rule configuration parameters) the operation of the NAT44 MUST be restricted to the available port numbers derived via the basic mapping rule.

10. IANA Considerations

This specification does not require any IANA actions.

11. Security Considerations

Spoofing attacks: With consistency checks between IPv4 and IPv6 sources that are performed on IPv4/IPv6 packets received by MAP nodes, MAP does not introduce any new opportunity for spoofing attacks that would not already exist in IPv6.

Denial-of-service attacks: In MAP domains where IPv4 addresses are shared, the fact that IPv4 datagram reassembly may be necessary introduces an opportunity for DOS attacks. This is inherent to address sharing, and is common with other address sharing approaches such as DS-Lite and NAT64/DNS64. The best protection against such attacks is to accelerate IPv6 deployment, so that, where MAP is supported, it is less and less used.

Routing-loop attacks: This attack may exist in some automatic tunneling scenarios are documented in [RFC6324]. They cannot exist with MAP because each BRs checks that the IPv6 source address of a received IPv6 packet is a CE address based on Forwarding Mapping Rule.

Attacks facilitated by restricted port set: From hosts that are not subject to ingress filtering of [RFC2827], some attacks are possible by an attacker injecting spoofed packets during ongoing transport connections ([RFC4953], [RFC5961], [RFC6056]. The attacks depend on guessing which ports are currently used by target hosts, and using an unrestricted port set is preferable, i.e. Using native IPv6 connections that are not subject to MAP port range restrictions. To minimize this type of attacks when using a restricted port set, the MAP CE's NAT44 filtering behavior SHOULD be "Address-Dependent Filtering". Furthermore, the MAP CEs

SHOULD use a DNS transport proxy function to handle DNS traffic, and source such traffic from IPv6 interfaces not assigned to MAP. Practicalities of these methods are discussed in Section 5.9 of [I-D.dec-stateless-4v6].

[RFC6269] outlines general issues with IPv4 address sharing.

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This document is the result of the IETF Softwire MAP design team effort and numerous previous individual contributions in this area:

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Appendix A. Examples

Example 1 - Basic Mapping Rule

Given the MAP domain information and an IPv6 address of
an endpoint:

```
End-user IPv6 prefix: 2001:db8:0012:3400::/56
Basic Mapping Rule:   {2001:db8:0000::/40 (Rule IPv6 prefix),
                       192.0.2.0/24 (Rule IPv4 prefix),
                       16 (Rule EA-bits length)}
PSID length:          (16 - (32 - 24) = 8. (Sharing ratio of 256)
PSID offset:          6 (default)
```

A MAP node (CE or BR) can via the BMR, or equivalent FMR,
determine the IPv4 address and port-set as shown below:

```
EA bits offset:       40
IPv4 suffix bits (p)  Length of IPv4 address (32) -
                      IPv4 prefix length (24) = 8
IPv4 address:         192.0.2.18 (0xc0000212)
PSID start:           40 + p = 40 + 8 = 48
PSID length:          o - p = (56 - 40) - 8 = 8
PSID:                 0x34

Available ports (63 ranges) : 1232-1235, 2256-2259, ..... ,
                              63696-63699, 64720-64723
```

The BMR information allows a MAP CE to determine (complete)
its IPv6 address within the indicated IPv6 prefix.

```
IPv6 address of MAP CE:  2001:db8:0012:3400:0000:c000:0212:0034
```

Example 2 - BR:

Another example can be made of a MAP BR,
configured with the following FMR when receiving a packet
with the following characteristics:

```
IPv4 source address:       1.2.3.4 (0x01020304)
IPv4 source port:          80
IPv4 destination address:  192.0.2.18 (0xc0000212)
IPv4 destination port:     1232

Configured Forwarding Mapping Rule: {2001:db8::/40 (Rule IPv6 prefix),
                                     192.0.2.0/24 (Rule IPv4 prefix),
                                     16 (Rule EA-bits length)}

IPv6 address of MAP BR:              2001:db8:ffff::1
```

The above information allows the BR to derive as follows
the mapped destination IPv6 address for the corresponding
MAP CE, and also the mapped source IPv6 address for
the IPv4 source address.

```
IPv4 suffix bits (p):  32 - 24 = 8 (18 (0x12))
PSID length:           8
PSID:                  0x34 (1232)
```

The resulting IPv6 packet will have the following key fields:

```
IPv6 source address:       2001:db8:ffff::1
IPv6 destination address:  2001:db8:0012:3400:0000:c000:0212:0034
```

Example 3 - FMR:

An IPv4 host behind the MAP CE (addressed as per the previous
examples) corresponding with IPv4 host 1.2.3.4 will have its
packets encapsulated by IPv6 using the IPv6 address of the BR
configured on the MAP CE as follows:

```
IPv6 address of BR used by MAP CE: 2001:db8:ffff::1
IPv4 source address:               192.0.2.18
IPv4 destination address:          1.2.3.4
IPv4 source port:                  1232
IPv4 destination port:             80
IPv6 source address of MAP CE:     2001:db8:0012:3400:0000:c000:0212:0034
IPv6 destination address:          2001:db8:ffff::1
```

Example 4 - Rule with no embedded address bits and no address sharing

```
End-User IPv6 prefix:  2001:db8:0012:3400::/56
Basic Mapping Rule:    {2001:db8:0012:3400::/56 (Rule IPv6 prefix),
                        192.0.2.1/32 (Rule IPv4 prefix),
                        0 (Rule EA-bits length)}
PSID length:           0 (Sharing ratio is 1)
PSID offset:           n/a
```

A MAP node (CE or BR) can via the BMR or equivalent FMR, determine the IPv4 address and port-set as shown below:

```
EA bits offset:       0
IPv4 suffix bits (p): Length of IPv4 address (32) -
                      IPv4 prefix length (32) = 0
IPv4 address:         192.0.2.1 (0xc0000201)
PSID start:           0
PSID length:          0
PSID:                 null
```

The BMR information allows a MAP CE also to determine (complete) its full IPv6 address by combining the IPv6 prefix with the MAP interface identifier (that embeds the IPv4 address).

```
IPv6 address of MAP CE:  2001:db8:0012:3400:0000:c000:0201:0000
```

Example 5 - Rule with no embedded address bits and address sharing (sharing ratio 256)

```
End-User IPv6 prefix:  2001:db8:0012:3400::/56
Basic Mapping Rule:    {2001:db8:0012:3400::/56 (Rule IPv6 prefix),
                        192.0.2.1/32 (Rule IPv4 prefix),
                        0 (Rule EA-bits length)}
PSID length:           8. (Provisioned with DHCP. Sharing ratio of 256)
PSID offset:           6  (Default)
PSID       :           0x20 (Provisioned with DHCP.)

A MAP node can via the BMR determine the IPv4 address and port-set
as shown below:

EA bits offset:        0
IPv4 suffix bits (p):  Length of IPv4 address (32) -
                       IPv4 prefix length (32) = 0
IPv4 address:          192.0.2.1 (0xc0000201)
PSID offset:           6
PSID length:           8
PSID:                  0x20

Available ports (63 ranges) : 1536-1551, 2560-2575, ..... ,
                              64000-64015, 65024-65039

The BMR information allows a MAP CE also to determine (complete)
its full IPv6 address by combining the IPv6 prefix with the MAP
interface identifier (that embeds the IPv4 address and PSID).

IPv6 address of MAP CE: 2001:db8:0012:3400:0000:c000:0212:0034

Note that the IPv4 address and PSID is not derived from the IPv6
prefix assigned to the CE, but provisioned separately using
e.g. DHCP.
```

Appendix B. A More Detailed Description of the Derivation of the Port Mapping Algorithm

This Appendix describes how the port mapping algorithm described in Section 5.1 was derived. The algorithm is used in domains whose rules allow IPv4 address sharing.

The basic requirement for a port mapping algorithm is that the port sets it assigns to different MAP CEs MUST be non-overlapping. A number of other requirements guided the choice of the algorithm:

- In keeping with the general MAP algorithm the port set MUST be derivable from a port set identifier (PSID) that can be embedded in the End-user IPv6 prefix.

- The mapping MUST be reversible, such that, given the port number,

the PSID of the port set to which it belongs can be quickly derived.

- The algorithm MUST allow a broad range of address sharing ratios.

- It SHOULD be possible to exclude subsets of the complete port numbering space from assignment. Most operators would exclude the system ports (0-1023). A conservative operator might exclude all but the transient ports (49152-65535).

- The effect of port exclusion on the possible values of the End-user IPv6 prefix (i.e., due to restrictions on the PSID value) SHOULD be minimized.

- For administrative simplicity, the algorithm SHOULD allocate the the same or almost the same number of ports to each CE sharing a given IPv4 address.

The two extreme cases that an algorithm satisfying those conditions might support are: (1) the port numbers are not contiguous for each PSID, but uniformly distributed across the allowed port range; (2) the port numbers are contiguous in a single range for each PSID. The port mapping algorithm proposed here is called the Generalized Modulus Algorithm (GMA) and supports both these cases.

For a given IPv4 address sharing ratio (R) and the maximum number of contiguous ports (M) in a port set, the GMA is defined as:

a. The port numbers (P) corresponding to a given PSID are generated by:

(1) ... P = (R * M) * i + M * PSID + j

where i and j are indices and the ranges of i, j, and the PSID are discussed in a moment.

b. For any given port number P, the PSID is calculated as:

(2) ... PSID = trunc((P modulo (R * M)) / M)

where trunc() is the operation of rounding down to the nearest integer.

Formula (1) can be interpreted as follows. First, the available port space is divided into blocks of size R * M. Each block is divided into R individual ranges of length M. The index i in formula (1) selects a block, PSID selects a range within that block, and the index j selects a specific port value within the range. On the basis of this interpretation:

- i ranges from ceil(N / (R * M)) to trunc(65536/(R * M)) - 1, where ceil is the operation of rounding up to the nearest integer and N is the number of ports (e.g., 1024) excluded from the lower end of the range. That is, any block containing excluded values is

discarded at the lower end, and if the final block has fewer than R * M values it is discarded. This ensures that the same number of ports is assigned to every PSID.

o PSID ranges from 0 to R - 1;

o j ranges from 0 to M - 1.

B.1. Bit Representation of the Algorithm

If R and M are powers of 2 (R = 2^k, M = 2^m), formula (1) translates to a computationally convenient structure for any port number represented as a 16-bit binary number. This structure is shown in Figure 9.

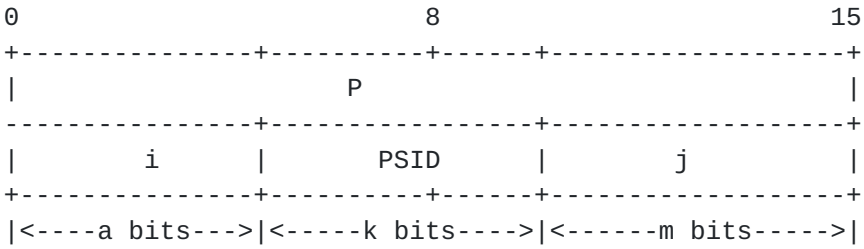

Figure 9: Bit Representation of a Port Number

As shown in the figure, the index value i of formula (1) is given by the first a = 16 - k - m bits of the port number. The PSID value is given by the next k bits, and the index value j is given by the last m bits.

For any port number, the PSID can be obtained by a bit mask operation.

Note that when M and R are powers of 2, 65536 divides evenly by R * M. Hence the final block is complete and the upper bound on i is exactly 65536/(R * M) - 1. The lower bound on i is still the minimum required to ensure that the required set of ports is excluded. No port numbers are wasted through discarding of blocks at the lower end if block size R * M is a factor of N, the number of ports to be excluded.

As a final note, the number of blocks into which the range 0-65535 is being divided in the above representation is given by 2^a. Hence the case where a = 0 can be interpreted as one where the complete range has been divided into a single block, and individual port sets are contained in contiguous ranges in that block. We cannot throw away the whole block in that case, so port exclusion has to be achieved by putting a lower bound equal to ceil(N / M) on the allowed set of PSID values instead.

B.2. GMA examples

For example, for R = 256, PSID = 0, offset: a = 6 and PSID length: k = 8 bits

Available ports (63 ranges) : 1024-1027, 2048-2051, ... ,
63488-63491, 64512-64515

For example, for R = 64, PSID = 0, a = 0 (PSID offset = 0 and PSID length = 6 bits), no port exclusion:

Available ports (1 range) : 0-1023

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