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                  Mapping of Address and Port (MAP)
               draft-mdt-softwire-mapping-address-and-port-03

Abstract

   This document describes a generic mechanism for mapping between IPv4
   addresses and IPv6 addresses and transport layer ports.

Status of this Memo

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

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

   This Internet-Draft will expire on August 2, 2012.

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1. Introduction

   The mechanism of mapping 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
   differences between these are the use of well-known IPv6 prefixes, or
   Service Provider assigned IPv6 prefixes, and the position of the
   embedded IPv4 bits in the IPv6 address. Teredo [RFC4380] added a
   twist to this to achieve NAT traversal by also encoding transport
   layer ports into the IPv6 address. 6rd, to achieve more efficient
   encoding, allowed for only the suffix of an IPv4 address to be
   embedded, with the IPv4 prefix being deduced from other provisioning
   mechanisms.

   NAT-PT [RFC2766](deprecated) combined with a DNS ALG used address
   mapping to put NAT state, namely the IPv6 to IPv4 binding encoded in
   an IPv6 address. This characteristic has been inherited by NAT64
   [RFC6146] and DNS64 [RFC6147] which rely on an address format defined
   in [RFC6052]. [RFC6052] specifies the algorithmic translation of an
   IPv6 address to IPv4 address. In particular, [RFC6052] specifies the
   address format to build IPv4-converted and IPv4-translatable IPv6
   addresses. RFC6052 discusses the transport of the port-set
   information in an IPv4-embedded IPv6 address but the conclusion was
   the following (excerpt from [RFC6052]):

   "There have been proposals to complement stateless translation with a
   port range feature. Instead of mapping an IPv4 address to exactly
   one IPv6 prefix, the options would allow several IPv6 nodes to share
   an IPv4 address, with each node managing a different set of ports.
   If a port-set extension is needed, it could be defined later, using
   bits currently reserved as null in the suffix."

   The commonalities of all these IPv6 over IPv4 mechanisms are:

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

   o Algorithmic or implicit address resolution for tunneling or
      encapsulation. Given an IPv6 destination address, an IPv4 tunnel
      endpoint address can be calculated. Likewise for translation, an

IPv4 address can be calculated from an IPv6 destination address
and vice versa.

o Embedding of an IPv4 address or part thereof and optionally
   transport layer ports 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 more generic mapping of IPv4
to IPv6 that can be used both for encapsulation (IPv4 over IPv6) and
for translation between the two protocols.

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

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

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

The unified mapping scheme described here supports translation mode,
encapsulation mode, in both mesh and hub and spoke topologies.

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 work is described in
[I-D.ietf-softwire-stateless-4v6-motivation].

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

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: A set of 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 MAP node in the domain has the same set of
                       rules.

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: Each node has a 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 the 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] 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 CE's and from BR's.

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.

IPv4 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.

MRT: MAP Rule table. Address and Port aware
                       datastructure, supporting longest match
                       lookups. The MRT is used by the MAP forwarding
                       function.

[4](). Architecture

A full IPv4 address or IPv4 prefix can be used like today, e.g. for
identifying an interface or as a DHCP pool. A shared IPv4 address on
the other hand, MUST NOT be used to identify an interface. While it
is theoretically possible to make host stacks and applications port-
aware, that is considered a too drastic change to the IP model
[RFC6250].

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. The NAPT MUST in turn be connected
to a MAP aware forwarding function, that does encapsulation/
decapsulation or translation to IPv6.

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 assigned CE's port-range.

The forwarding function uses the MRT to make forwarding decisions.
The table consist of the mapping rules. An entry in the table
consists of an IPv4 prefix and PSID. The normal best matching prefix
algorithm is used. With a maximum key length of 48 (32 + 16). E.g.
with a sharing ratio of 64 (6 bit PSID length) a host route for this
CE would be a /38 (32 + 6).

[5]. Mapping Rules

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 itself with an IPv4 address, IPv4 prefix or shared IPv4 address from an End-user IPv6 prefix. 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 or prefix. Additional mapping rules can be specified to allow for e.g. multiple different IPv4 subnets to exist within the domain. Additional mapping rules are recognized by having a Rule IPv6 prefix different from the base End-user IPv6 prefix.

Traffic outside of the domain (IPv4 address not matching (using longest matching prefix) any Rule IPv4 prefix in the Rules database) will be forward using the Default mapping rule. The Default mapping rule maps outside destinations to the BR's IPv6 address or prefix.

There are three types of mapping rules:

1. Basic Mapping Rule - used for IPv4 prefix, address or port set assignment. There can only be one Basic Mapping Rule per End-user IPv6 prefix. The Basic Mapping Rule is used to configure the MAP IPv6 address or prefix.

    *   Rule IPv6 prefix (including prefix length)

    *   Rule IPv4 prefix (including prefix length)

    *   Rule EA-bits length (in bits)

    *   Rule Port Parameters (optional)

2. Forwarding Mapping Rule - used for forwarding. The Basic Mapping Rule is also a Forwarding Mapping Rule. Each Forwarding Mapping Rule will result in an entry in the MRT for the Rule IPv4 prefix.

    *   Rule IPv6 prefix (including prefix length)

    *   Rule IPv4 prefix (including prefix length)

    *   Rule EA-bits length (in bits)

    *   Rule Port Parameters (optional)

   3. Default Mapping Rule - used for destinations outside the MAP
       domain. A 0.0.0.0/0 entry is installed in the MRT for this rule.

       * Rule IPv6 prefix (including prefix length)

       * Rule BR IPv4 address

   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 Rule database. The rule is then used for IPv4 prefix,
   address or shared address assignment.

   A MAP IPv6 address (or prefix) 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 MRT are installed for all the
   Forwarding Mapping Rules and an IPv4 default route for the Default
   Mapping Rule.

   In hub and spoke mode, all traffic MUST be forwarded using the
   Default Mapping Rule.

5.1. Port mapping algorithm

   Different Port-Set Identifiers (PSID) MUST have non-overlapping port-
   sets. The two extreme cases are: (1) the port numbers are not
   contiguous for each PSID, but uniformly distributed across the port
   range (0-65535); (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 sharing ratio (R) and the maximum number of contiguous
   ports (M), the GMA algorithm is defined as:

   1. The port number (P) of a given PSID (K) is composed of:

   $P = R * M * j + M * K + i$

       Where:

       * PSID: K = 0 to R - 1

       * Port range index: j = (4096 / M) / R to ((65536 / M) / R) - 1,
          if the port numbers (0 - 4095) are excluded.

```
      *  Contiguous Port index: i = 0 to M - 1
```

2. The PSID (K) of a given port number (P) is determined by:

```
K = (floor(P/M)) % R
```

   Where:

   * % is the modulus operator

   * floor(arg) is a function that returns the largest integer not
      greater than arg.

5.1.1. Bit Representation of the Algorithm

   Given a sharing ratio (R=2^k), the maximum number of contiguous ports
   (M=2^m), for any PSID (K) and available ports (P) can be represented
   as:

```
0                               8                          15
+---------------+----------+------+------------------+
|                        P                           |
+---------------+----------------+------------------+
|     A (j)     |   PSID (K)     |       M  (i)      |
+---------------+----------+------+------------------+
|<----a bits--->|<-----k bits---->|<------m bits----->|
```


                   Figure 1: Bit representation
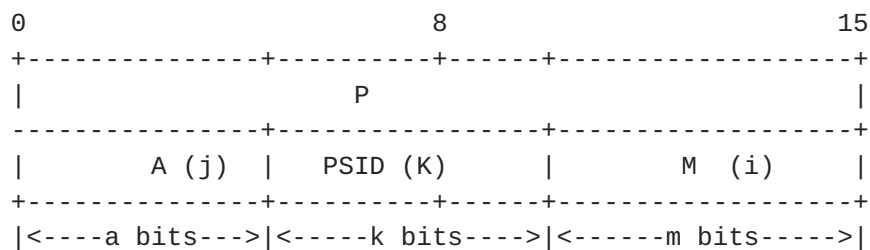
   Where j and i are the same indexes defined in the port mapping
   algorithm.

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

   For a > 0, j MUST be larger than 0. This ensures that the algorithm
   excludes the system ports ([I-D.ietf-tsvwg-iana-ports]). For a = 0,
   j MAY be 0 to allow for the provisioning of the system ports.

5.1.2. GMA examples

For example, for R = 1024, PSID offset: a = 4 and PSID length: k = 10
bits

```
          Port-set-1                 Port-set-2
PSID=0    | 4096, 4097, 4098, 4099, | 8192,  8193,  8194,  8195, | ...
PSID=1    | 4100, 4101, 4102, 4103, | 8196,  8197,  8198,  8199, | ...
PSID=2    | 4104, 4105, 4106, 4107, | 8200,  8201,  8202,  8203, | ...
PSID=3    | 4108, 4109, 4110, 4111, | 8204,  8205,  8206,  8207, | ...
...
PSID=1023| 8188, 8189, 8190, 8191, | 12284, 12285, 12286, 12287,| ...
```

                Example 1: with offset = 4 (a = 4)

For example, for R = 64, a = 0 (PSID offset = 0 and PSID length = 6
bits):

```
          Port-set
PSID=0    | [   0 - 1023]
PSID=1    | [1024 - 2047]
PSID=2    | [2048 - 3071]
PSID=3    | [3072 - 4095]
...
PSID=63  | [64512 - 65535]
```

                Example 2: with offset = 0 (a = 0)

5.1.3. GMA Provisioning Considerations

The number of offset bits (a) and excluded ports are optionally
provisioned via the "Rule Port Mapping Parameters" in the Basic
Mapping Rule.

The defaults are:

o Excluded ports : 0-4095

o Offset bits (a) : 4

To simplify the GMA port mapping algorithm the defaults are chosen so
that the PSID field starts on a nibble boundary and the excluded port
range (0-1023) is extended to 0-4095.

5.2. Basic mapping rule (BMR)

```
 |      n bits         |  o bits   | m bits  |  128-n-o-m bits      |
 +--------------------+----------+---------+-----------+----------+
 |  Rule IPv6 prefix  |  EA bits  |subnet ID|    interface ID      |
 +--------------------+----------+---------+-----------------------+
 |<---  End-user IPv6 prefix  --->|
```
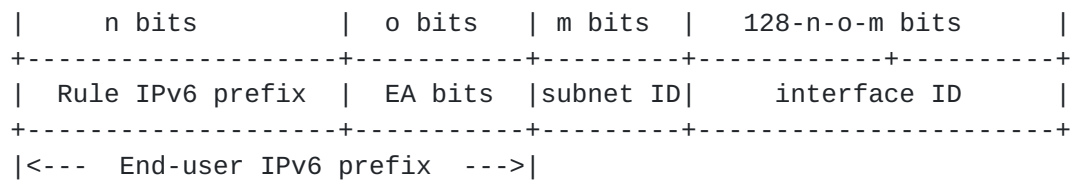
                    Figure 2: IPv6 address format

The Embedded Address bits (EA bits) are unique per end user within a
Rule IPv6 prefix. 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 can contain a full or part
of an IPv4 prefix or address, and in the shared IPv4 address case
contains a Port-Set Identifier (PSID).

The MAP IPv6 address is created by concatenating the End-user IPv6
prefix with the MAP subnet-id and the interface-id as specified in
Section 6.

The MAP subnet ID is defined to be the first subnet (all bits set to
zero). A MAP node MUST reserve the first IPv6 prefix in a End-user
IPv6 prefix for the purpose of MAP.

                      Shared IPv4 address:

      | r bits | p bits | | q bits |
      +------------+--------------------+   +-----------+
      | Rule IPv4 | IPv4 Address suffix | |Port-Set ID |
      +------------+--------------------+   +-----------+
      | 32 bits |
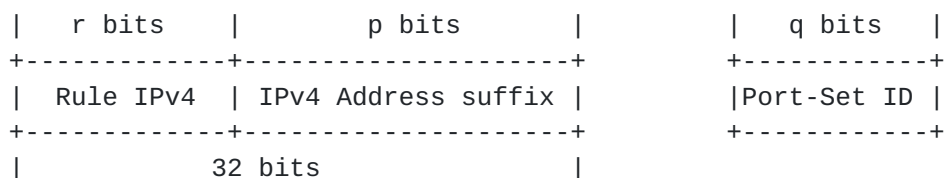
                    Figure 3: Shared IPv4 address

                    Complete IPv4 address:

         | r bits | p bits |
         +------------+--------------------+
         | Rule IPv4 | IPv4 Address suffix |
         +------------+--------------------+
         | 32 bits |
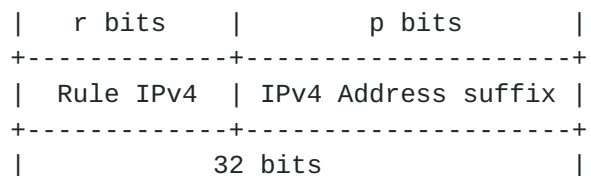
                    Figure 4: Complete IPv4 address
```

IPv4 prefix:

```
        |   r bits    |         p bits      |
        +-------------+---------------------+
        |  Rule IPv4  | IPv4 Address suffix |
        +-------------+---------------------+
        |             < 32 bits             |
```

Figure 5: IPv4 prefix

The length of 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, are 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. 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.

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.

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: o - p.

In the following examples, only the suffix (last 8 bits) of the IPv4 address is embedded in the EA bits (r = 24), while the IPv4 prefix (first 24 bits) is given in the BMR Rule IPv4 prefix.

   Example:

  Given:
   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)}
   Sharing ratio: 256 (16 - (32 - 24) = 8. 2^8 = 256)
   PSID offset: 4

  We get IPv4 address and port-set:
   EA bits offset: 40
   IPv4 suffix bits (p): Length of IPv4 address (32) -
                          IPv4 prefix length (24) = 8
   IPv4 address: 192.0.2.18

   PSID start: 40 + p = 40 + 8 = 48
   PSID length: o - p = 16 (56 - 40) - 8 = 8
   PSID: 0x34
   Port-set-1:   4928, 4929, 4930, 4931, 4932, 4933, 4934, 4935,
                          4936, 4937, 4938, 4939, 4940, 4941, 4942, 4943
   Port-set-2:   9024, 9025, 9026, 9027, 9028, 9029, 9030, 9031,
                          9032, 9033, 9034, 9035, 9036, 9037, 9038, 9039
   ...
   Port-set-15:   62272, 62273, 62274, 62275,
                          62276, 62277, 62278, 62279,
                          62280, 62281, 62282, 62283,
                          62284, 62285, 62286, 62287,

5.3. Forwarding mapping rule (FMR)

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

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

```
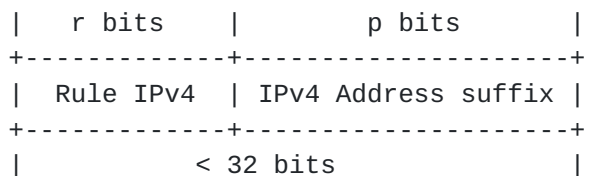 |       32 bits       |        |     16 bits        |
 +------------------------+         +------------------+
 | IPv4 destination address |       |  IPv4 dest port  |
 +------------------------+         +------------------+
               :         :       ___/          :
               | p bits  |      /  q bits   :
               +---------+         +-----------+
               |IPv4  sufx|        |Port-Set ID |
               +---------+         +-----------+
                \         /    ____/     _____/
                  \      :  __/    _____/
                    \    : /     /
 |     n bits      | o bits  | m bits  |   128-n-o-m bits      |
 +-----------------+---------+---------+-----------+---------+
 |  Rule IPv6 prefix  | EA bits  |subnet ID|    interface ID       |
 +-----------------+---------+---------+-----------+---------+
 |<---  End-user IPv6 prefix  --->|
```

                     Figure 6: Deriving of MAP IPv6 address

     Example:

       Given:
        IPv4 destination address: 192.0.2.18
        IPv4 destination port: 9030
        Forwarding Mapping Rule: {2001:db8:0000::/40 (Rule IPv6 prefix),
                                    192.0.2.0/24 (Rule IPv4 prefix),
                                    16 (Rule EA-bits length)}
        PSID offset: 4

       We get IPv6 address:
        IPv4 suffix bits (p): 32 - 24 = 8 (18 (0x12))
        PSID length: 8
        PSID: 0x34 (9030 (0x2346))
        EA bits: 0x1234
        MAP IPv6 address: 2001:db8:0012:3400:00c0:0002:1200:3400

5.4. Default mapping rule (DMR)

   The Default Mapping rule is used to reach IPv4 destinations outside
   of the MAP domain. Traffic using this rule will be sent from a CE to
   a BR.

   The Rule IPv4 prefix in the DMR is: 0.0.0.0/0. The Rule IPv6 prefix
   is the IPv6 address or prefix of the BR. Which is used, is dependent
   on the mode used. For example translation requires that the IPv4
   destination address is encoded in the BR IPv6 address, so only a

prefix is used in the DMR to allow for a generated interface
identifier. For the encapsulation mode the Rule IPv6 prefix can be
the full IPv6 address of the BR.

There MUST be only one Default Mapping Rule within a MAP domain.


```
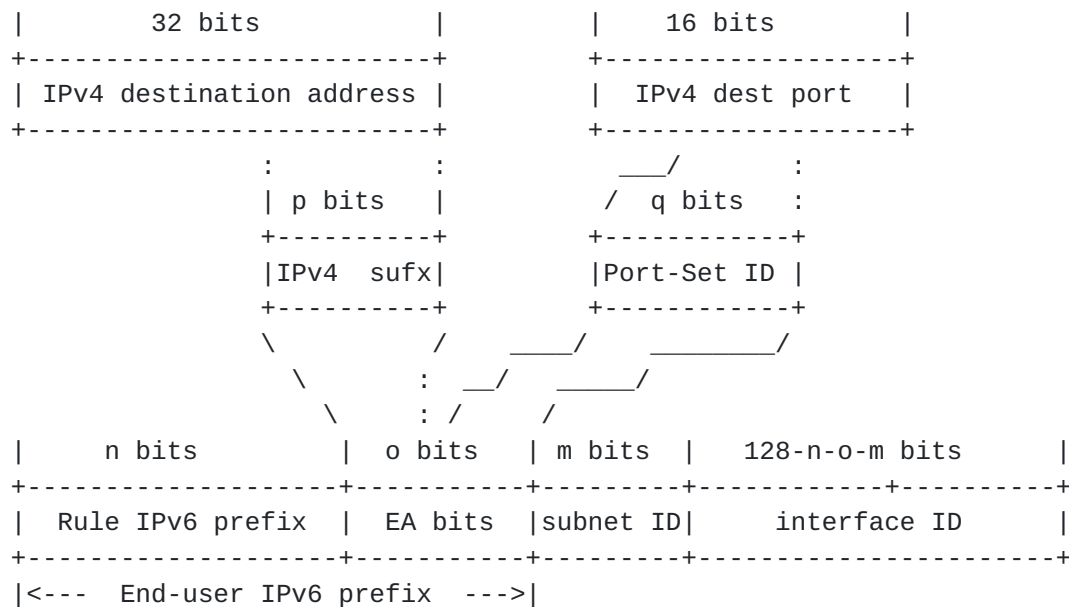 Default Mapping Rule:
      {2001:db8:0001:0000:&lt;interface-id>:/128 (Rule IPv6 prefix),
       0.0.0.0/0 (Rule IPv4 prefix),
       192.0.2.1 (BR IPv4 address)}
```

                    Example 3: Default Mapping Rule

In most implementations of a routing table, the next-hop address must
be of the same address family as the prefix. To satisfy this
requirement a BR IPv4 address is included in the rule. Giving a
default route in the IPv4 routing table:


```
   0.0.0.0 -> 192.0.2.1, MAP-Interface0
```


6. The IPv6 Interface Identifier

The Interface identifier format is based on the format specified in
section 2.2 of [RFC6052], with the added PSID format field.

In an encapsulation solution, an IPv4 address and port is mapped to
an IPv6 address. This is the address of the tunnel end point of the
receiving MAP CE. For traffic outside the MAP domain, the IPv6
tunnel end point address is the IPv6 address of the BR. The
interface-id used for all MAP nodes in the domain MUST be
deterministic.

When translating, the destination IPv4 address is translated into a
corresponding IPv6 address. In the case of traffic outside of the
MAP domain, it is translated to the BR's IPv6 prefix. For the BR to
be able to reverse the translation, the full destination IPv4 address
must be encoded in the IPv6 address. The same thing applies if an
IPv4 prefix is encoded in the IPv6 address, then the reverse
translator needs to know the full destination IPv4 address, which has
to be encoded in the interface-id.

The encoding of the full IPv4 address into the interface identifier,
both for the source and destination IPv6 addresses have been shown to
be useful for troubleshooting.

```
+--+---+---+---+---+---+---+---+---+
|PL|   8  16  24  32  40  48  56   |
+--+---+---+---+---+---+---+---+---+
|64| u | IPv4 address  |  PSID | 0 |
+--+---+---+---+---+---+---+---+---+
```

Figure 7

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. For translation mode the End-user IPv6 prefix MUST be 64 or
shorter.

7. IANA Considerations

This specification does not require any IANA actions.

8. Security Considerations

Specific security considerations with the MAP mechanism are detailed
in the encapsulation and translation documents [I-D.mdt-map-t/
I-D.mdt-map-e].

[RFC6269] outlines general issues with IPv4 address sharing.

9. Contributors

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11. References

11.1. Normative References

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          January 2012.

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