                       Recommendations for IPv6 in
            Third Generation Partnership Project (3GPP) Standards

Status of this Memo

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Abstract

   This document contains recommendations from the Internet Engineering
   Task Force (IETF) IPv6 Working Group to the Third Generation
   Partnership Project (3GPP) community regarding the use of IPv6 in the
   3GPP standards. Specifically, this document recommends that the 3GPP
   specify that multiple prefixes may be assigned to each primary PDP
   context, require that a given prefix must not be assigned to more
   than one primary PDP context, and allow 3GPP nodes to use multiple
   identifiers within those prefixes, including randomly generated
   identifiers.

   The IPv6 Working Group supports the use of IPv6 within 3GPP and
   offers these recommendations in a spirit of open cooperation between
   the IPv6 Working Group and the 3GPP community. Since the original
   publication of this document as an Internet-Draft, the 3GPP has
   adopted the primary recommendations of this document.

Conventions Used In This Document

   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 BCP 14, RFC 2119
   [KEYWORD].

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1. Introduction

   In May 2001, the IPv6 Working Group (WG) held an interim meeting in
   Redmond, WA to discuss the use of IPv6 within the 3GPP standards.
   The first day of the meeting was a joint discussion with 3GPP, during
   which an architectural overview of 3GPP's usage of IPv6 was
   presented, and there was much discussion regarding particular aspects
   of IPv6 usage within 3GPP. At that meeting, a decision was made to
   form a design team to write a document offering advice from the IPv6
   WG to the 3GPP community, regarding their use of IPv6. This document
   is the result of that effort.

   This document offers recommendations to the 3GPP community from the
   IETF IPv6 Working Group. It is organized into three main sections:

      1. An introduction (this section) that provides background
         information regarding the IETF IPv6 WG and the 3GPP and
         includes a high-level overview of the technologies discussed in
         this document.

2. Recommendations from the IPv6 WG to the 3GPP community. These
   can be found in section 2.

3. Further work items that should be considered by the IPv6 WG.
   These items are discussed in section 3.

It is the purpose of this document to provide advice from the IPv6
Working Group to the 3GPP community. We have limited the contents of
this document to items that are directly related to the use of IPv6
within 3GPP. This document defines no standards, and it is not a
definitive source of information regarding IPv6 or 3GPP. We have not
chosen to explore 3GPP-related issues with other IETF protocols
(i.e., SIP, IPv4, etc.), as they are outside the scope of the IPv6
Working Group.

The IPv6 Working Group fully supports the use of IPv6 within 3GPP,
and we encourage 3GPP implementers and operators to participate in
the IETF process. We are offering these suggestions in a spirit of
open cooperation between the IPv6 Working Group and the 3GPP
community, and we hope that our ongoing cooperation will help to
strengthen both sets of standards.

The 3GPP address allocation information in this document is based on
the 3GPP document TS 23.060 version 4.1.0 [OLD-TS23060]. At the 3GPP
plenary meeting TSG #15 in March 2002, the 3GPP adopted the two
primary recommendations contained in this document, allocating a
unique prefix to each primary PDP context when IPv6 stateless address
autoconfiguration is used, and allowing the terminals to use multiple
interface identifiers. These changes were retroactively applied from
3GPP release 99 onwards, in TS23.060 versions 3.11.0, 4.4.0 and 5.1.0
[NEW-TS23060].

1.1 What is the 3GPP?

The Third Generation Partnership Project (3GPP) is a global
standardization partnership founded in late 1998. Its Organizational
Partners have agreed to co-operate in the production of technical
specifications for a Third Generation Mobile System, based on the
evolved GSM core networks.

The 3GPP Organizational Partners consist of several different
standardization organizations: ETSI from Europe, Standards Committee
T1 Telecommunications (T1) in the USA, China Wireless
Telecommunication Standard Group (CWTS), Korean Telecommunications
Technology Association (TTA), the Association of Radio Industries and
Businesses (ARIB), and the Telecommunication Technology
Committee(TTC) in Japan.

The work is coordinated by a Project Co-ordination Group (PCG), and
structured into Technical Specification Groups (TSGs). There are
five TSGs: Core Network (TSG CN), Radio Access Networks (TSG RAN),
Services and System Aspects (TSG SA), GSM/EDGE Radio Access Network
(GERAN), and the Terminals (TSG T). The TSGs are further divided
into Working Groups (WGs). The technical work is done in the working
groups, and later approved in the TSGs.

3GPP working methods are different from IETF working methods. The
major difference is where the majority of the work is done. In 3GPP,
the work is done in face-to-face meetings, and the mailing list is
used mainly for distributing contributions, and for handling
documents that were not handled in the meeting, due to lack of time.
Decisions are usually made by consensus, though voting does exist.
However, it is rather rare to vote. 3GPP documents are public and
can be accessed via the 3GPP web site [3GPP-URL].

1.2 What is the IETF?

The Internet Engineering Task Force (IETF) is a large, open,
international community of network designers, operators, vendors, and
researchers, concerned with the evolution of the Internet
architecture and the smooth operation of the Internet. The IETF is
also the primary standards body developing Internet protocols and
standards. It is open to any interested individual. More
information about the IETF can be found at the IETF web site [IETF-
URL].

The actual technical work of the IETF is done in working groups,
organized by topic into several areas (e.g., routing, transport,
security, etc.). The IPv6 Working Group is chartered within the
Internet area of the IETF. Much of the work is handled via mailing
lists, and the IETF holds meetings three times per year.

1.3 Terminology

This section defines the 3GPP and IETF terminology used in this
document. The 3GPP terms and their meanings have been taken from
[TR21905].

1.3.1   3GPP Terminology

APN   Access Point Name. The APN is a logical name referring
             to a GGSN and an external network.

CS   Circuit Switched

GERAN   GSM/EDGE Radio Access Network

GGSN   Gateway GPRS Support Node. A router between the GPRS
              network and an external network (i.e., the Internet).

GPRS   General Packet Radio Services

GTP-U   General Tunneling Protocol - User Plane

MT   Mobile Termination. For example, a mobile phone
              handset.

PDP   Packet Data Protocol

PDP Context   A PDP connection between the UE and the GGSN.

PS   Packet Switched

SGSN   Serving GPRS Support Node

TE   Terminal Equipment. For example, a laptop attached
              through a 3GPP handset.

UE   User Equipment (TE + MT + USIM). An example would be
              a mobile handset with a USIM card inserted and a
              laptop attached.

UMTS   Universal Mobile Telecommunications System

USIM   Universal Subscriber Identity Module. Typically, a
              card that is inserted into a mobile phone handset.

UTRAN   Universal Terrestrial Radio Access Network

1.3.2   IETF Terminology

IPv6   Internet Protocol version 6 [RFC 2460]

NAS   Network Access Server

NAT   Network Address Translator

NAT-PT   Network Address Translation with Protocol Translation.
              An IPv6 transition mechanism. [NAT-PT]

PPP   Point-to-Point Protocol [PPP]

SIIT   Stateless IP/ICMP Transition Mechanism [SIIT]

1.4 Overview of the IPv6 Addressing Architecture

   The recommendations in this document are primarily related to IPv6
   address assignment. To fully understand the recommended changes, it
   is necessary to understand the IPv6 addressing architecture, and
   current IPv6 address assignment mechanisms.

   The IPv6 addressing architecture represents a significant evolution
   from IPv4 addressing [ADDRARCH]. It is required that all IPv6 nodes
   be able to assemble their own addresses from interface identifiers
   and prefix information. This mechanism is called IPv6 Host
   Autoconfiguration [AUTOCONF], and it allows IPv6 nodes to configure
   themselves without the need for stateful configuration servers (i.e.,
   DHCPv6) or statically configured addresses.

   Interface identifiers can be globally unique, such as modified EUI-64
   addresses [ADDRARCH], or non-unique, such as randomly generated
   identifiers. Hosts that have a globally unique identifier available
   may also choose to use randomly generated addresses for privacy
   [PRIVADDR] or for other reasons. IPv6 hosts are free to generate new
   identifiers at any time, and Duplicate Address Detection (DAD) is
   used to protect against the use of duplicate identifiers on a single
   link [IPV6ND].

   A constant link-local prefix can be combined with any interface
   identifier to build an address for communication on a locally
   attached link. IPv6 routers may advertise additional prefixes
   (site-local and/or global prefixes)[IPV6ND]. Hosts can combine
   advertised prefixes with their own interface identifiers to create
   addresses for site-local and global communication.

   IPv6 introduces architectural support for scoped unicast addressing
   [SCOPARCH]. A single interface will typically have multiple
   addresses for communication within different scopes: link-local,
   site-local and/or global [ADDRARCH]. Link-local addresses allow for
   local communication, even when an IPv6 router is not present. Some
   IPv6 protocols (i.e., routing protocols) require the use of link-
   local addresses. Site-local addressing allows communication to be
   administratively contained within a single site. Link-local or
   site-local connections may also survive changes to global prefix
   information (e.g., site renumbering).

   IPv6 explicitly associates each address with an interface.
   Multiple-interface hosts may have interfaces on more than one link or
   in more than one site. Links and sites are internally identified
   using zone identifiers. Proper routing of non-global traffic and
   proper address selection are ensured by the IPv6 scoped addressing
   architecture [SCOPARCH].

   IPv6 introduces the concept of privacy addresses [PRIVADDR]. These
   addresses are generated from an advertised global prefix and a
   randomly generated identifier, and are used for anonymous access to
   Internet services. Applications control the generation of privacy
   addresses, and new addresses can be generated at any time.

   The IPv6 site renumbering specification [SITEREN] relies upon the
   fact that IPv6 nodes will generate new addresses when new prefixes
   are advertised on the link, and that they will deprecate addresses
   that use deprecated prefixes.

   In the future, additional IPv6 specifications may rely upon the
   ability of IPv6 nodes to use multiple prefixes and/or multiple
   identifiers to dynamically create new addresses.

1.5 An IP-Centric View of the 3GPP System

   The 3GPP specifications define a Third Generation Mobile System. An
   overview of the packet switched (PS) domain of the 3GPP Release 99
   system is described in the following sections. The authors hope that
   this description is sufficient for the reader who is unfamiliar with
   the UMTS packet switched service, to understand how the UMTS system
   works, and how IPv6 is currently defined to be used within it.

1.5.1   Overview of the UMTS Architecture

   The UMTS architecture can be divided into two main domains -- the
   packet switched (PS) domain, and the circuit switched (CS) domain.
   In this document, we will concentrate on the PS domain, or General
   Packet Radio Services (GPRS).

```
   ------
  |  TE  |
   ------
     |
    +R
     |
   ------   Uu  -----------   Iu  -----------   Gn  -----------   Gi
  |  MT  |--+--|   UTRAN   |--+--|   SGSN    |--+--|   GGSN    |--+--
   ------       -----------       -----------       -----------
    (UE)
```
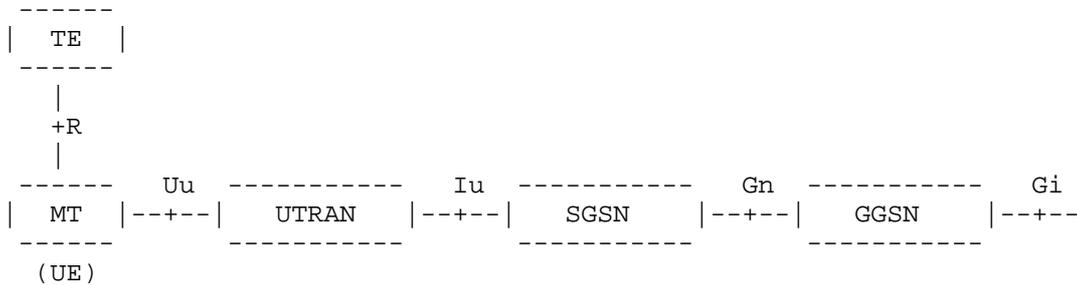
                   Figure 1: Simplified GPRS Architecture

```
    ------
   |      |
   | App  |- - - - - - - - - - - - - - - - - - - - - - -(to app peer)
   |      |
   |------|                                              -------------
   |  IP  |- - - - - - - - - - - - - - - - - - - - -|     IP      |->
   | v4/6 |                                         |    v4/6     |
   |------|        -------------     -------------  |------       |
   |      |       | \ Relay / |     | \ Relay / |  |     |       |
   |      |       |  \     /  |     |  \     /  |  |     |       |
   |      |       |   \   /   |     |   \   /   |  |     |       |
   | PDCP |- - -| PDCP\ /GTP_U|- - -|GTP_U\ /GTP_U|- - -|GTP_U |       |
   |      |       |     |     |     |     |     |  |     |       |
   |------|       |------|------|     |------|------|  |------|       |
   |      |       |     | UDP  |- - -| UDP  | UDP  |- - -| UDP  |       |
   |      |       |     |------|     |------|------|  |------|       |
   | RLC  |- - -| RLC  |  IP  |- - -|  IP  |  IP  |- - -|  IP  |       |
   |      |       |     | v4/6 |     | v4/6 | v4/6 |  | v4/6 |       |
   |------|       |------|------|     |------|------|  |------|------|
   | MAC  |       | MAC  | AAL5 |- - -| AAL5 |  L2  |- - -|  L2  |  L2  |
   |------|       |------|------|     |------|------|  |------|------|
   | L1   |- - -| L1   | ATM  |- - -| ATM  |  L1  |- - -|  L1  |  L1  |
    ------         -------------     -------------     -------------

       UE              UTRAN              SGSN              GGSN
    (handset)
```
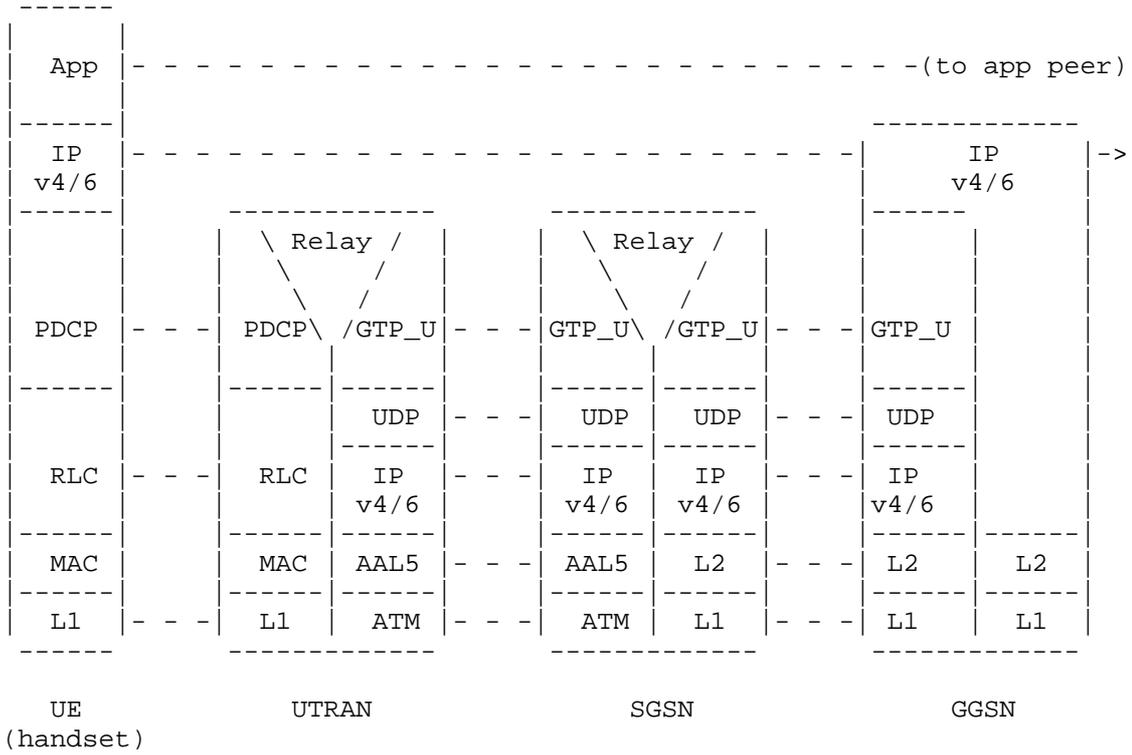
                    Figure 2: GPRS Protocol Stacks

```
    ------
   |      |
   | App. |- - - - - - - - - - - - - - - - - - - - (to app peer)
   |      |
   |------|
   |      |
   |  IP  |- - - - - - - - - - - - - - - - - - - - (to GGSN)
   | v4/6 |
   |      |       |         |
   |------|       |-------------|
   |      |       |  \ Relay /  |
   |      |       |   \     /   |
   |      |       |    \   /    |
   |      |       |     \ / PDCP|- - - (to UTRAN)
   |      |       |      |      |
   | PPP  |- - -| PPP |------|
   |      |       |      | RLC |- - - (to UTRAN)
   |      |       |      |------|
   |      |       |      | MAC |
   |------|       |------|------|
   | L1a  |- - -| L1a | L1b |- - - (to UTRAN)
    ------        -------------
      TE              MT
   (laptop)        (handset)
```
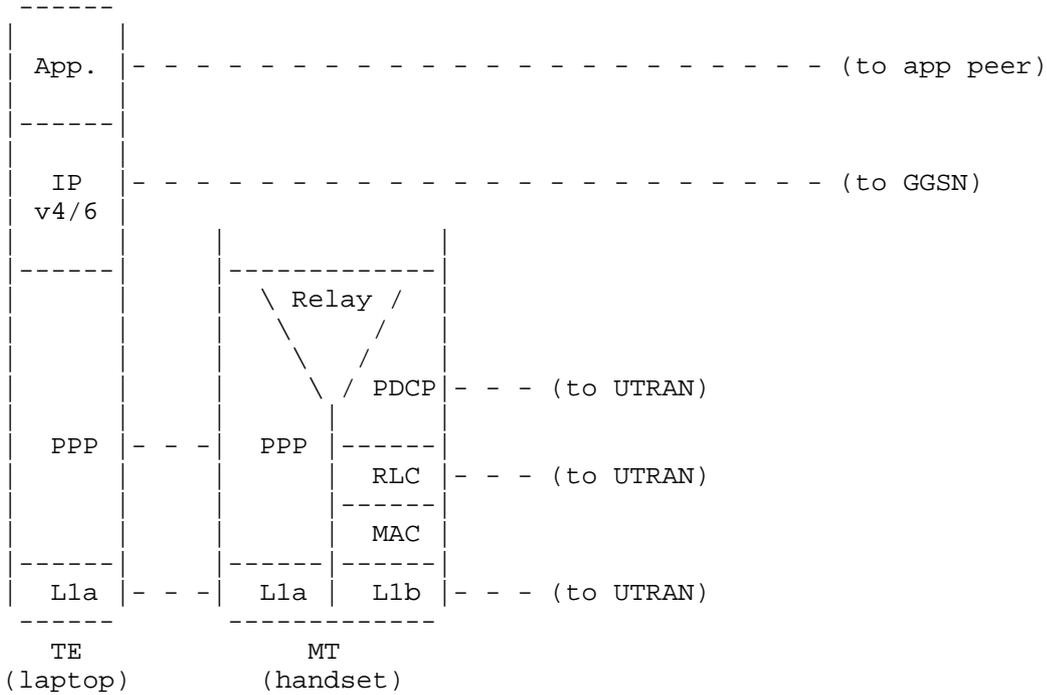
                  Figure 3: Laptop Attached to 3GPP Handset

   The GPRS core network elements, shown in Figures 1 and 2, are the
   User Equipment (UE), Serving GPRS Support Node (SGSN), and Gateway
   GPRS Support Node (GGSN). The UTRAN comprises Radio Access Network
   Controllers (RNC) and the UTRAN base stations.

   GGSN: A specialized router that functions as the gateway between the
          GPRS network and the external networks, e.g., Internet. It
          also gathers charging information about the connections. In
          many ways, the GGSN is similar to a Network Access Server
          (NAS).

   SGSN: The SGSN's main functions include authentication,
          authorization, mobility management, and collection of billing
          information. The SGSN is connected to the SS7 network and
          through that, to the Home Location Register (HLR), so that it
          can perform user profile handling, authentication, and
          authorization.

GTP-U: A simple tunnelling protocol running over UDP/IP and used to
        route packets between RNC, SGSN and GGSN within the same, or
        between different, UMTS backbone(s). A GTP-U tunnel is
        identified at each end by a Tunnel Endpoint Identifier (TEID).

Only the most significant elements of the GPRS system are discussed
in this document. More information about the GPRS system can be
found in [OLD-TS23060].

1.5.2   The PDP Context

The most important 3GPP concept in this context is a PDP Context. A
PDP Context is a connection between the UE and the GGSN, over which
the packets are transferred. There are two kinds of PDP Contexts --
primary, and secondary.

The primary PDP Context initially defines the link to the GGSN. For
instance, an IP address is assigned to each primary PDP Context. In
addition, one or more secondary PDP Contexts can be added to a
primary PDP Context, sharing the same IP address. These secondary
PDP Contexts can have different Quality of Service characteristics
than the primary PDP Context.

Together, a primary PDP Context and zero or more secondary PDP
Contexts define, in IETF terms, a link. GPRS links are point-to-
point. Once activated, all PDP contexts have equal status, meaning
that a primary PDP context can be deleted while keeping the link
between the UE and the GGSN, as long as there are other (secondary)
PDP contexts active for the same IP address.

There are currently three PDP Types supported in GPRS -- IPv4, IPv6,
and PPP. This document will only discuss the IPv6 PDP Type.

There are three basic actions that can be performed on a PDP Context:
PDP Context Activation, Modification, and Deactivation. These
actions are described in the following.

Activate PDP Context

     Opens a new PDP Context to a GGSN. If a new primary PDP
     Context is activated, there is a new link created between a UE
     and a GGSN. A UE can open multiple primary PDP Contexts to one
     or more GGSNs.

Modify PDP Context

     Changes the characteristics of a PDP Context, for example QoS
     attributes.

Deactivate PDP Context

> Deactivates a PDP Context. If a primary PDP Context and all
> secondary PDP contexts associated with it are deactivated, a
> link between the UE and the GGSN is removed.

The APN is a name which is logically linked to a GGSN. The APN may
identify a service or an external network. The syntax of the APN
corresponds to a fully qualified domain name. At PDP context
activation, the SGSN performs a DNS query to find out the GGSN(s)
serving the APN requested by the terminal. The DNS response contains
a list of GGSN addresses from which the SGSN selects one (in a
round-robin fashion).

```
                   ---------                      --------
                  |         |                    | GGSN   |
                  |         |         LINK 1     |        |
                  |          -======== PDP Context A ========-   - - -> ISP X
                  |         |          |                |   |
                  |         |          |                |   |
                  |         |          |                |   |
                  |         |          |                |   |
                  |          /======= PDP Context B ======\    |
                  |        - |          LINK 2            | -   - - -> ISP Y
                  |          \======= PDP Context C ======/     |
                  |         |          |                |   |
                  |   MT    |          |                 --------
                  | (handset)|         |
                  |         |          |                 --------
   --------       |         |          |                | GGSN   |
  |        |      |         |          |       LINK 3   |        |
  |        |      |          -======== PDP Context D ========-   |
  |   TE   |      |         |          |                |   |
  | (laptop)|     |         |          |                |    - - -> ISP Z
  |        |      |         |          |       LINK 4   |        |
  |         -====PPP===-------------- PDP Context E ========-    |
  |        |      |         |          |                |   |
  |        |      |         |          |                |   |
   --------       |          ---------                  |        |
                   ---------                             --------
```
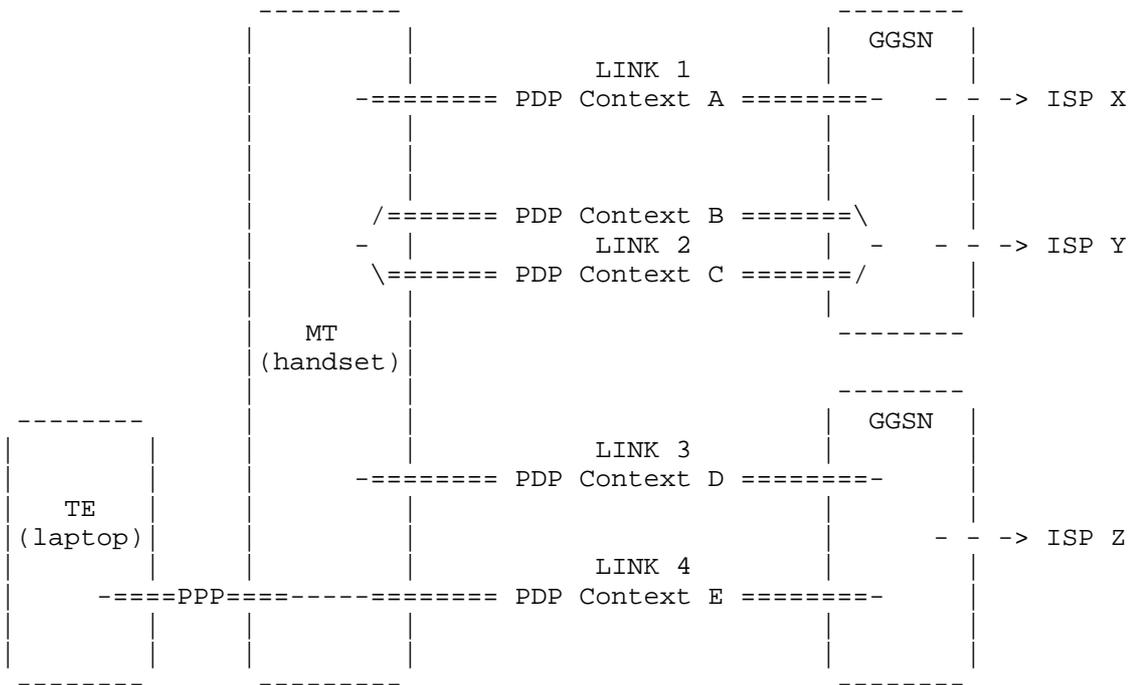
                 Figure 3: Correspondence of PDP Contexts to IPv6 Links

1.5.3   IPv6 Address Autoconfiguration in GPRS

GPRS supports static and dynamic address allocation. Two types of
dynamic address allocation are supported -- stateless, and stateful.
Stateful address configuration uses an external protocol to connect
to a server that gives the IP address, e.g., DHCP.

The stateless IPv6 autoconfiguration works differently in GPRS than
in Ethernet networks. GPRS nodes have no unique identifier, whereas
Ethernet nodes can create an identifier from their EUI-48 address.
Because GPRS networks are similar to dialup networks, the stateless
address autoconfiguration in GPRS was based on PPPv6 [PPPV6].

3GPP address autoconfiguration has the following steps:

  1. The Activate PDP Context message is sent to the SGSN (PDP
     Type=IPv6, PDP Address = 0, etc.).

  2. The SGSN sends a Create PDP Context message to the GGSN with
     the above parameters.

  3. GGSN chooses an interface identifier for the PDP Context and
     creates the link-local address. It answers the SGSN with a
     Create PDP Context response (PDP Address = link-local address).

  4. The SGSN sends an Activate PDP Context accept message to the UE
     (PDP Address = link-local address).

  5. The UE keeps the link-local address, and extracts the interface
     identifier for later use. The UE may send a Router
     Solicitation message to the GGSN (first hop router).

  6. After the PDP Context Activation, the GGSN sends a Router
     Advertisement to the UE.

  7. The UE should be configured not to send a Neighbor Solicitation
     message. However, if one is sent, the GGSN will silently
     discard it.

  8. The GGSN updates the SGSN with the whole IPv6 address.

Each connected handset or laptop will create a primary PDP context
for communication on the Internet. A handset may create many primary
and/or secondary PDP contexts throughout the life of its connection
with a GGSN.

Within 3GPP, the GGSN assigns a single 64-bit identifier to each
primary PDP context. The GGSN also advertises a single /64 prefix to
the handset, and these two items are assembled into a single IPv6
address. Later, the GGSN modifies the PDP context entry in the SGSN
to include the whole IPv6 address, so that the SGSN can know the
single address of each 3GPP node (e.g., for billing purposes). This
address is also used in the GGSN to identify the PDP context
associated with each packet. It is assumed that 3GPP nodes will not

generate any addresses, except for the single identifier/prefix
combination assigned by the GGSN. DAD is not performed, as the GGSN
will not assign the same address to multiple nodes.

2 Recommendations to the 3GPP

In the spirit of productive cooperation, the IPv6 Working Group
recommends that the 3GPP consider three changes regarding the use of
IPv6 within GPRS. Specifically, we recommend that the 3GPP:

   1. Specify that multiple prefixes may be assigned to each primary
      PDP context,

   2. Require that a given prefix must not be assigned to more than
      one primary PDP context, and

   3. Allow 3GPP nodes to use multiple identifiers within those
      prefixes, including randomly generated identifiers.

Making these changes would provide several advantages for 3GPP
implementers and users:

   Laptops that connect to 3GPP handsets will work without any
   software changes. Their implementation of the standard IPv6 over
   PPP, address assignment, and autoconfiguration mechanisms will
   work without any modification. This will eliminate the need for
   vendors and operators to build and test special 3GPP drivers and
   related software. As currently specified, the 3GPP standards will
   be incompatible with laptop implementations that generate their
   own identifiers for privacy or other purposes.

   IPv6 software implementations could be used in 3GPP handsets
   without any modifications to the IPv6 protocol mechanisms. This
   will make it easier to build and test 3GPP handsets.

   Applications in 3GPP handsets will be able to take advantage of
   different types of IPv6 addresses (e.g., static addresses,
   temporary addresses for privacy, site-scoped addresses for site
   only communication, etc.)

   The GPRS system will be better positioned to take advantage of new
   IPv6 features that are built around the current addressing
   architecture.

2.1 Limitations of 3GPP Address Assignment

   The current 3GPP address assignment mechanism has the following
   limitations:

The GGSN only advertises a single /64 prefix, rather than a set of
prefixes. This will prevent the participation of 3GPP nodes
(e.g., handsets or 3GPP-attached laptops) in IPv6 site
renumbering, or in other mechanisms that expect IPv6 hosts to
create addresses based on multiple advertised prefixes.

A 3GPP node is assigned a single identifier and is not allowed to
generate additional identifiers. This will prevent the use of
privacy addresses by 3GPP nodes. This also makes 3GPP mechanisms
not fully compliant with the expected behavior of IPv6 nodes,
which will result in incompatibility with popular laptop IPv6
stacks. For example, a laptop that uses privacy addresses for web
browser connections could not currently establish a web browser
connection over a 3GPP link.

These limitations could be avoided by enabling the standard IPv6
address allocation mechanisms in 3GPP nodes. The GGSN could
advertise one or more prefixes for the local link in standard IPv6
Router Advertisements, and IPv6 addresses could be assembled, as
needed, by the IPv6 stack on the handset or laptop. An interface
identifier could still be assigned by the GGSN, as is currently
specified in the 3GPP standards. However, the handset or laptop
could generate additional identifiers, as needed for privacy or other
reasons.

2.2 Advertising Multiple Prefixes

For compliance with current and future IPv6 standards, the IPv6 WG
recommends that the 3GPP allow multiple prefixes to be advertised for
each primary PDP context. This would have several advantages,
including:

3GPP nodes could participate in site renumbering and future IPv6
mechanisms that rely on the use of multiple global prefixes on a
single link.

Site-local prefixes could be advertised on 3GPP links, if desired,
allowing for site-constrained communication that could survive
changes to global prefix information (e.g., site renumbering).

2.3 Assigning a Prefix to Only One Primary PDP Context

The IPv6 WG recommends that the 3GPP treat a primary PDP context,
along with its secondary PDP contexts, as a single IPv6 link, and
that the GGSN view each primary PDP context as a single subnet.
Accordingly, a given global (or site-local) prefix should not be
assigned to more than one PDP context.

Because multiple IPv6 hosts may attach through a 3GPP handset, the
IPv6 WG recommends that one or more /64 prefixes should be assigned
to each primary PDP context. This will allow sufficient address
space for a 3GPP-attached node to allocate privacy addresses and/or
route to a multi-link subnet [MULTLINK], and will discourage the use
of NAT within 3GPP-attached devices.

2.3.1   Is a /64 per PDP Context Too Much?

If an operator assigns a /64 per PDP context, can we be assured that
there is enough address space for millions of mobile devices? This
question can be answered in the positive using the Host Density (HD)
Ratio for address assignment efficiency [HD]. This is a measure of
the number of addresses that can practically and easily be assigned
to hosts, taking into consideration the inefficiencies in usage
resulting from the various address assignment processes. The HD
ratio was empirically derived from actual telephone number and data
network address assignment cases.

We can calculate the number of easily assignable /64's making the
following assumptions:

   An HD ratio of 0.8 (representing the efficiency that can be
   achieved with no particular difficulty).

   Only addresses with the 3-bit prefix 001 (the Aggregatable Global
   Unicast Addresses defined by RFC 2373) are used, resulting in 61
   bits of assignable address space.

Using these assumptions, a total of 490 trillion (490×10^{12}) /64
prefixes can be assigned. This translates into around 80,000 PDP
Contexts per person on the earth today. Even assuming that a
majority of these IPv6 /64 prefixes will be used by non-3GPP
networks, there is still clearly a sufficient number of /64 prefixes.

Given this, it can be safely concluded that the IPv6 address space
will not be exhausted if /64 prefixes are allocated to primary PDP
contexts.

For more information regarding policies for IPv6 address assignment,
refer to the IAB/IESG recommendations regarding address assignment
[IABAA], and the APNIC, ARIN and RIPE address allocation policy
[AAPOL].

2.3.2   Prefix Information in the SGSN

   Currently, the 3GPP standards allow only one prefix and one
   identifier for each PDP context. So, the GGSN can send a single IPv6
   address to the SGSN, to be used for billing purposes, etc.

   Instead of using the full IPv6 address to identify a PDP context, the
   IPv6 WG recommends that the SGSN be informed of each prefix that is
   currently assigned to a PDP context. By assigning a prefix to only
   one primary PDP context, the SGSN can associate a prefix list with
   each PDP context.

2.4 Multiple Identifiers per PDP Context

   The IPv6 WG also recommends that the 3GPP standards be modified to
   allow multiple identifiers, including randomly generated identifiers,
   to be used within each assigned prefix. This would allow 3GPP nodes
   to generate and use privacy addresses, and would be compatible with
   future IPv6 standards that may depend on the ability of IPv6 nodes to
   generate new interface identifiers for communication.

   This is a vital change, necessary to allow standards-compliant IPv6
   nodes to connect to the Internet through 3GPP handsets, without
   modification. It is expected that most IPv6 nodes, including the
   most popular laptop stacks, will generate privacy addresses. The
   current 3GPP specifications will not be compatible with those
   implementations.

3 Additional IPv6 Work Items

   During our work on this document, we have discovered several areas
   that could benefit from further informational or standards-track work
   within the IPv6 Working Group.

   The IPv6 WG should work to define a point-to-point architecture and
   specify how the standard IPv6 address assignment mechanisms are
   applicable to IPv6 over point-to-point links. We should also review
   and clarify the IPv6 over PPP specification [PPP] to match the
   current IPv6 addressing architecture [ADDRARCH].

   The IPv6 WG should consider publishing an "IPv6 over PDP Contexts"
   (or similar) document. This document would be useful for developers
   writing drivers for IPv6 stacks to work over 3GPP PDP Contexts.

   The IPv6 working group should undertake an effort to define the
   minimal requirements for all IPv6 nodes.

4 Security Considerations

   This document contains recommendations on the use of the IPv6
   protocol in 3GPP standards. It does not specify a protocol, and it
   introduces no new security considerations.

Appendix A: Analysis of Findings

   This section includes some analysis that may be useful to
   understanding why the IPv6 working group is making the above
   recommendations. It also includes some other options that were
   explored, and the reasons why those options were less suitable than
   the recommendations outlined above.

A.1 Address Assignment Solutions

   In order to allow for the configuration and use of multiple IPv6
   addresses per primary PDP Context having different interface
   identifiers, some modifications to the current 3GPP specifications
   would be required.

   The solutions to achieve this were evaluated against the following
   factors:

      - Scarcity and high cost of wireless spectrum
      - Complexity of implementation and state maintenance
      - Stability of the relevant IETF standards
      - Impact on current 3GPP standards

   Two solutions to allow autoconfiguration of multiple addresses on the
   same primary PDP Context were considered:

   1. Assign one or more entire prefixes (/64s) to a PDP Context upon
      PDP Context activation and allow the autoconfiguration of
      multiple addresses.

      a) The assignment may be performed by having the GGSN advertise
         one or more /64 prefixes to the mobile device.

      b) The assignment may be performed by building "prefix
         delegation" functionality into the PDP Context messages or
         by using layer 3 mechanisms such as [PREFDEL]. In this way,
         the prefix is not assigned to the link between the GGSN and
         the mobile device (as in 1a), but it is assigned to the
         mobile device itself. Note that [PREFDEL] cannot be
         considered stable and has not, at this stage, been adopted
         by the IPv6 WG as a WG document.

   2. Share the same prefix between multiple PDP Contexts connected
      to the same GGSN (and APN). Given that mobile devices may
      generate multiple addresses using more than one interface
      identifier, this would require DAD for the newly generated
      addresses over the air interface, and a proxy DAD, function
      which would increase the complexity and the amount of state to

        be kept in the GGSN. Also, the GGSN would need to determine
        when the temporary addresses are no longer in use, which would
        be difficult. One possible solution could be using periodic
        unicast neighbor solicitations for the temporary addresses
        [IPV6ND].

   Considering all the factors when evaluating the solutions, the
   recommendation is to use Solution 1a. This solution requires the
   least modification to the current 3GPP standards and maintains all
   the advantages of the other solutions.

   Effectively, this would mean that each APN in a GGSN would have a
   certain number of /64 prefixes that can be handed out at PDP context
   Activation, through Router Advertisements. Therefore, instead of
   using the full IPv6 address to identify a primary PDP context, the
   IPv6 WG recommends that the GGSN use the entire prefix (together with
   other 3GPP specific information) and that the SGSN be informed of the
   prefixes that are assigned to a PDP context. By assigning a given
   prefix to only one primary PDP context, the GGSN and SGSN can
   associate a prefix list with each PDP context, as needed.

   Note that the recommended solution does not imply or assume that the
   mobile device is a router. The MT is expected to use the /64 for
   itself and may also use this prefix for devices attached to it.
   However, this is not necessary if each device behind the MT is
   connected to a separate primary PDP Context and therefore can use a
   /64, which is not shared with other devices. The MT is also expected
   to handle DAD locally for devices attached to it (e.g., laptops)
   without forwarding Neighbor Solicitations over the air to the GGSN.

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