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Abstract:

This deliverable is a report on the integration and test of the software developed on the Head End router, Home Gateway and Set Top Box.

Keywords:

Autoconfiguration, IPv6, PLC, QoS, Test.

Revision History

The following table describes the main changes done in the document since created.

Revision	Date	Description	Author (Organization)
v1.0	19/03/2004	Document creation	Jean-Mickael Guérin (6WIND)
v1.1	20/06/2004	Autoconf: Radius section added	Jean-Mickael Guérin (6WIND)
v1.2	13/07/2004	Autoconf: DHCPv6 section added	Jean-Mickael Guérin (6WIND)
v1.3	25/07/2004	Autoconf: Integration details with Radius, Routing protocols, DNS	Jean-Mickael Guérin (6WIND)
v1.4	02/09/2004	Fill summary, conclusions and references (to be completed)	Jean-Mickael Guérin (6WIND)
v1.5	19/10/2004	Completed sections on PLC autoconf and PLC QoS	Chano Gómez (DS2)
v1.6	05/11/2004	Integration and Testing of Ipv6 on a Set Top Box	Alan Delaney (Pace)
v1.7	07/11/2004	Final PSC review	Jordi Palet (Consulintel)

Executive Summary

This deliverable is an integration and test report on network functions developed during 6POWER project. Three kinds of equipments are involved in PLC network: head end, home gateway and set-top-box.

Concerning the head end, the most important development is IPv6 autoconfiguration feature. This development requires full cooperation with several network functions like DNS proxy, Radius authorization, and routing protocols, among others. Network traces and dump of routing tables are given to show these requirements are met.

The home gateway and CPE have been enhanced to support QoS and autoconfiguration features.

The STB has fully upgraded to support IPv6, which previously was not available, including multicast capabilities.

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1. INTRODUCTION

WP4 aims at designing and developing the devices able to support a large IPv6 deployment over PLC. These developments include the Head End, the Home Gateway, a Set-Top Box and some adaptations for end devices. This deliverable is a report on integration and test of this software.

Section 2 focus on integration effort of IPv6 functions in charge of autoconfigurating the PLC network: DHCPv6 prefix delegation, DNS proxy, Routing, Stateless autoconfiguration on LAN.

Section 3 introduces the QoS and autoconfiguration features of the home gateway and CPE, while section 4 focus in the IPv6 adaptation realized in the Set-Top-Box.

2. HEAD END

2.1 Autoconfiguration integration and test

IPv6 autoconfiguration in 6POWER PLC network involves several network configuration parameters to be delivered automatically to CPE.

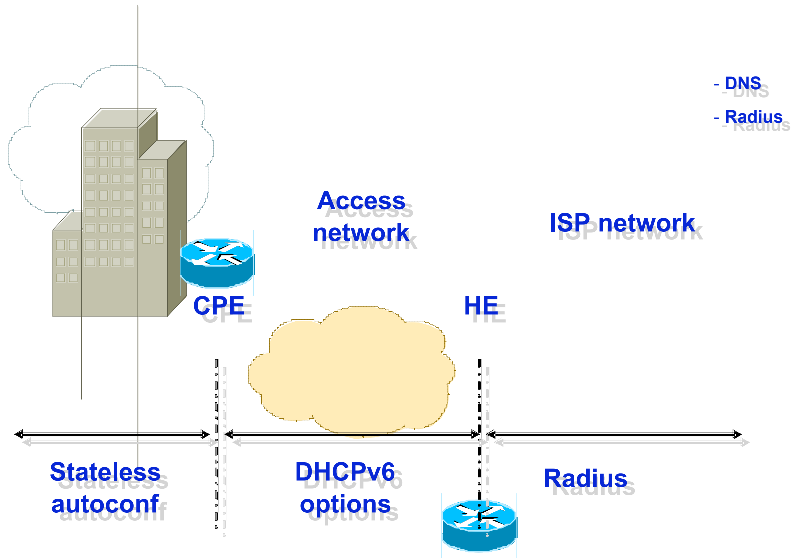

Figure 2-1: Autoconfiguration Overview

In terms of implementation, these parameters are provided by a set of network functions that interact each other and thus must be integrated:

- Prefix delegation: DHCPv6 defines a standard mechanism to delegate IPv6 prefixes to CPE.
- Routing: New delegated IPv6 prefixes must be propagated in routing.
- Radius access: Clients' IPv6 prefixes are stored in Radius database.
- DNS proxy: CPE needs to proxy DNS request for clients.
- Stateless autoconfiguration: CPE needs to advertise on each link a prefix 64 bits length derived from the prefix acquired with prefix delegation.

2.1.1 DHCPv6 and Prefix delegation

DHCPv6 implementation is based on RFC3315 and RFC3633, the former defining the core protocol and the latter the prefix delegation option.

2.1.1.1 DHCPv6 client on CPE

The CPE is the requesting router according to the terminology of RFC3633. The CPE must support the following options:

- SOLICIT: To locate servers.
- REQUEST: To request configuration parameters, including IP addresses, from a specific server.
- RENEW: Sent to the server that originally provided the client's addresses and configuration parameters, to extend the lifetimes on the addresses assigned to the client and to update other configuration parameters.
- REBIND: Sent to any available server to extend the lifetimes on the addresses assigned to the client and to update other configuration parameters; this message is sent after a client receives no response to a Renew message.
- ADVERTISE: To learn servers location
- REPLY: To process reply message from the server.
- RAPID_COMMIT: This option allows the client to reduce the number of messages from four (SOLICIT/ADVERTISE/REQUEST/REPLY) to two (SOLICIT/REPLY).

2.1.1.2 DHCPv6 server on HE

The HE is the delegating router according to the terminology of RFC3633. The HE must process the previous mentioned request options (SOLICIT, REQUEST, RENEW, REBIND) and reply with ADVERTISE option to SOLICIT messages and with REPLY option to other messages, embedding network configuration according to client's configuration.

2.1.2 Integration with routing

DHCPv6 has to cope with routing protocols on both CPE and HE.

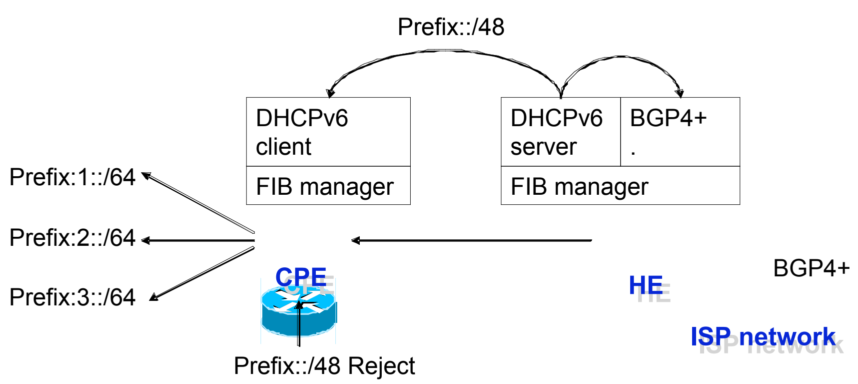

Figure 2-2: Prefix Delegation and Routing

2.1.2.1 CPE and routing

The Prefix assigned (P::/n) to the CPE defines an IPv6 site, where n<=64. The CPE must not forward on upstream that link IPv6 packets whose destination address is within this prefix. The goal is to avoid ping-pong traffic between the CPE and the upstream router (HE).

To prevent this case to happen the CPE needs to add a reject route for this prefix. Hosts sending to IPv6 address that are not on-link for the CPE will then receive an ICMPv6 Error Host Unreachable.

This is the reason why DHCPv6 client implementation has been enhanced to cooperate with routing. In 6WINDGate routing architecture, route addition or deletion must pass through the FIB (Forwarding Information Base) manager, a master agent in charge of building the FIB from the information provided by routing protocols. This DHCPv6 implementation becomes a client of this FIB manager.

On a successful exchange between a CPE and a HE, for prefix delegation, we can check that this route has been properly added by displaying the FIB, for instance for the delegation of prefix 3ffe:ffff:1234::/48:

```
router{show-route}show ipv6 route
Codes: K - kernel route, C - connected, S - static, R - RIPng,
O - OSPFv3,
       B - BGP, D - DEP, * - FIB route.
…

D>* 3ffe:ffff:1234::/48 [10/0] via ::1, lo0, rej, 00:37:26
C>* 3ffe:ffff:1234:1::/64 is directly connected, eth0_0
C>* 3ffe:ffff:1234:2::/64 is directly connected, eth1_0
```

2.1.2.2 HE and routing

The Head End is interconnected to the ISP network and is likely running a routing protocol like BGP4+ or OSPFv3. With the prefix delegation mechanism, IPv6 prefixes, typically 48 bits length, are assigned to a CPE, resulting in new routing entries: Each HE has to add a static route to each CPE for the IPv6 prefix learnt dynamically with DHCPv6.

Thus IPv6 prefixes assigned to CPE need to be injected into ISP routing protocol. That’s why we have to make the DHCPv6 server cooperating with FIB manager. A new route’s type has been defined in the FIB manager, aside BGP, RIPNG, OSPFv3. This new type has been named DEP, standing for Delegated prefix. When the DHCPv6 server adds a route toward a CPE, the FIB manager then adds this route as well. Other protocols like BGP4+ or OSPFv3 may be configured to redistribute this type of route, with a command like: redistribute dep.

2.1.3 Integration with DNS

IPv6 DNS servers are learnt dynamically by mean of a specific DHCPv6 option (RFC3646). For IPv6 address to name resolution, hosts on CPE’s LAN send DNS requests to the CPE which plays the role of a DNS proxy.

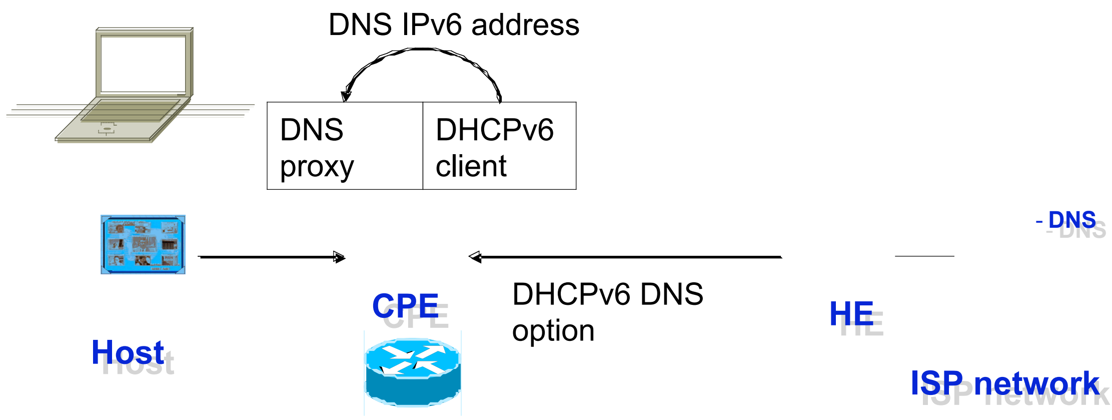

Figure 2-3: Prefix Delegation and DNS Proxy

Thus the DNS proxy function needs to interact with the DHCPv6 client on the CPE. It has been enhanced so its notified with the DNS configuration information from DHCPv6, namely the IPv6 addresses of forwarders.

2.1.4 Integration with Radius

The IPv6 prefixes to delegate to the CPEs are learnt dynamically by the DHCPv6 server, via exchange with a Radius server. As specified in RFC2865, "An Access-Request SHOULD contain a User-Name attribute. It MUST contain either a NAS-IP-Address attribute or a NAS-Identifier attribute (or both)". We choose to use NAS identifier represented by the FQDN (full qualified domain name). In addition to the NAS identifier, User attribute is filled with CPE MAC address extracted from the DHCPv6 request. Finally the DHCPv6 server sends a radius request including:

- NAS identifier attribute, filled with FQDN of DHCPv6 server.
- User attribute, filled with MAC address from DHCPv6 client request.
- Pass attribute: Always 'default'.

To check the presence of NAS identifier inside radius request, we use the network-monitoring tool ‘tcpdump’. Follows a trace upon DHCPv6 prefix request from CPE whose MAC address is 00:04:57:00:7b:06.

```
3ffe:304:124:6902::8.1026 > 3ffe:304:124:6902::6.1812: [udp sum
ok] rad-access-req 67 [id 207] Attr[  User{000457007b06} Pass
NAS_id{lisa.rd.6sons.net} ] (len 75, hlim 64)
```

That means that the DHCPv6 server (3ffe:304:124:6902::8) sends an access request to radius server (3ffe:304:124:6902::6, port 1812) embedding NAS identifier, the full qualified domain name (“lisa.rd.6son.net”).

In order to make the DHCPv6 server and Radius server exchange possible, a radius client has been integrated into the DHCPv6 server. This radius client is able to send access requests and process replies from the radius server, over IPv4 and IPv6.

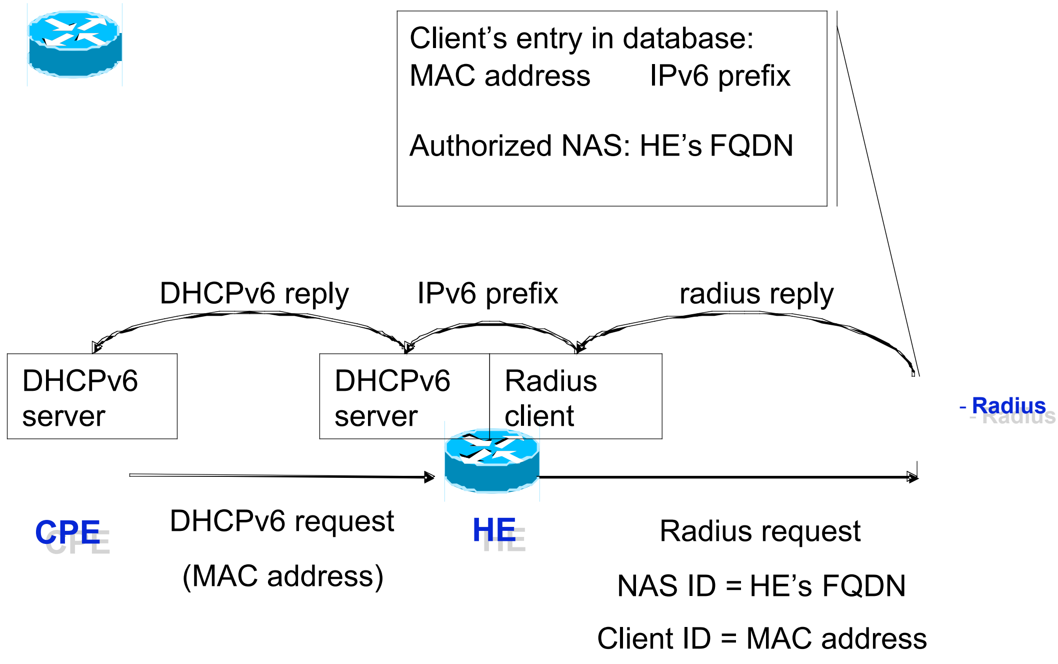

Figure 2-4: Prefix Delegation and Radius

2.1.5 Integration with stateless autoconfiguration

After a successful DHCPv6 exchange, the CPE gets a prefix P::/n (n<=64). Then the CPE has to subnet this delegated prefix and assign the longer prefixes to links in the subscriber's network. In the typical 6POWER scenario the CPE subnets a single delegated /48 into /64 prefixes on each LAN interface.

To make the hosts on the LAN able to perform stateless autoconfiguration, the CPE has to send periodic ICMPv6 router advertisements (RFC2462). The router advertisement function is achieved by means of a dedicated agent in 6WINDGate routing architecture, namely rtadvd.

Thus the DHCPv6 client and the rtadvd agent have to cooperate. Rtadvd has been enhanced with UNIX socket server interface in order to receive dynamically the configuration parameters. UNIX socket client interface has been added to the DHCPv6 client too. The DHCPv6 client use this channel to communicate the IPv6 prefix to be sent on each interface.

Follows the network trace of a Router Advertisement, upon the receipt of delegated prefix 3ffe:ffff:1234::/48:

```
01:05:31.179904 fe80::209:c0ff:fe30:420e > ff02::1: icmp6:
router advertisement(chlim=0, pref=medium, router_ltime=1800,
reachable_time=0, retrans_time=0)(src lladdr:
00:09:c0:30:42:0e)(prefix info: LA
valid_ltime=7200,preferred_ltime=7200,prefix=3ffe:ffff:1234:2::/
64)(advint: advint=30000) (len 64, hlim 255)
                        6000 0000 0040 3aff fe80 0000 0000 0000
                        0209 c0ff fe30 420e ff02 0000 0000 0000
                        0000 0000 0000 0001 8600 3d46 0000 0708
```

```
0000 0000 0000 0000 0101 0009 c030 420e
0304 40c0 0000 1c20 0000 1c20 0000 0000
3ffe ffff 1234 0002 0000 0000 0000 0000
0701 0000 0000 7530
```

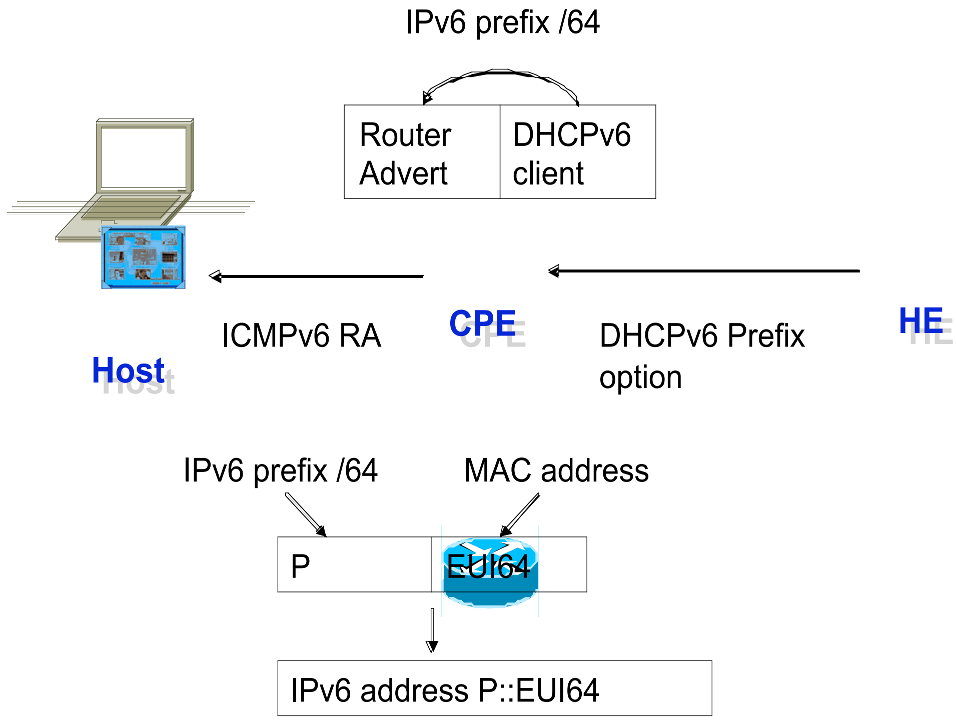

Figure 2-5: Prefix Delegation and Hosts Autoconfiguration

The hosts connected on the Ethernet LAN are now able to auto-configure global and unique IPv6 addresses on their own. Given a MAC address or a random 64 bits, usually the hosts will build a 64 bits identifier (EUI64). Then IPv6 address is the concatenation of IPv6 prefix /64 received in router advertisement and this identifier.

3. HOME GATEWAY AND CPE

3.1 PLC autoconfiguration enhancements

3.1.1 Features

Several autoconfiguration features have been included in the present release of the system firmware:

- Node autodiscovery: The HE and the repeaters are able to detect new nodes added to the network. New nodes are given an invited profile (see below) until the authentication procedure is completed.
- Invited profile: Newly detected nodes are given the invited service profile. This service profile provides basic PLC connectivity to support the authentication procedure, but does not allow transmission of data packets to the new node.
- Authentication protocol: The HE and the repeaters are able to initiate a connection to a RADIUS server to retrieve the profile index that defines the network and system parameters to be used with the new user. The credentials presented to the RADIUS server are the MAC of the node and the name of the HE or repeater that has found it. Only authorized nodes can make direct requests to the RADIUS server.
- User profiles: Nodes that succeed in the authentication procedure receive a valid profile identifier that determines the characteristics of the network connection. Profiles are used to categorize the different types of services offered by an ISP. Nodes that fail the authentication will remain as invited or receive a default profile.
- IP configuration: Once the network is set up, the hosts connected to the user modem can start the IP address configuration process. Depending on the network configuration, either IPv6 stateless autoconfiguration or IPv4/IPv6 stateful configuration (DHCP) is performed.
- Telnet remote access: Telnet-based access to the equipment for maintenance can be authenticated against a RADIUS server. This allows having a centralized control of the passwords, instead of a local setting for each PLC device.

3.1.2 Requirements

The following list summarizes the way the system addresses the general requirements:

- **Zero configuration.** The equipment requires very little manual configuration: only the link and the gains have to be set manually. This procedure can be incorporated in the device set-up, given that each link requires a specific type of card to be installed.
- **Optional autoconfiguration.** The network provider can choose whether to enable or disable these features in a configuration file. Equipment can be delivered with this option set by default.
- **Flexibility.** The equipment can be used to build different network topologies, although the changing topology is not yet supported.
- **Security.** The authenticity of a node is backed-up by two identifiers: The MAC address of the node and the NAS-Id of the immediate master that has found it. The network provider can allow the access only if the node hangs from a specific repeater, thus preventing traffic imbalance due to users movement without notice. In addition, the MAC

address is a unique identifier that is written in the user modem's non-volatile memory, and whose writing procedure is not known by the end-user.

- **Configurability.** Multiple user profiles are allowed and users may be moved from one profile to another when required.
- **Interoperability with IPv6 autoconfiguration.** Once the PLC-level autoconfiguration process is performed and all basic layer-1 and layer-2 parameters are correctly setup, the IPv6 autoconfiguration process is performed as usual.

3.1.3 Process Description

A detailed description of the autoconfiguration process is presented in deliverable D2.5. A brief overview is included hereafter.

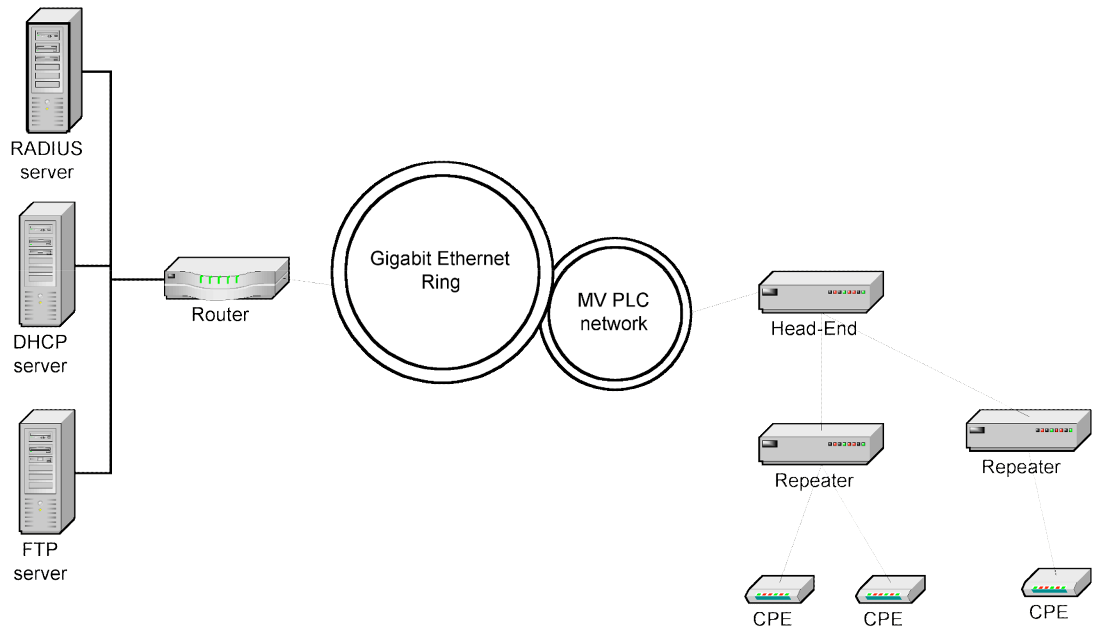

Figure 3-1: Elements Involved in the Autoconfiguration Process

When a CPE is added to the network, the following actions occur:

1. The CPE finds the link where the master is transmitting. The master recognizes the CPE and gets its MAC address.

2. The master initiates an authentication procedure against a Radius server.

3. The radius server looks the MAC address in its database and returns the profile to be used in each particular case.

4. The master reconfigures the connection according to the profile returned by the Radius server. It configures VLAN, QoS, BW, etc.

5. Once the CPE has network access, the hosts connected to it initiate the IP configuration process using either IPv6 autoconfiguration or DHCPv4/v6 protocol.

6. If using DHCP, the server looks up the MAC address of the host connected to the CPE in the database and returns the IP configuration: IP, netmask, gateway and the URL and name of an eventual configuration file.

7. In the case of the VoIP host, it downloads a configuration file from the FTP server. This file contains the settings for the VoIP network.

The same process can be applied for a repeater or a head-end. In this case, the configuration file will contain additional parameters for the configuration of the equipment.

3.1.4 Large-Scale deployment

When a network provider faces a large network deployment, some automation mechanisms need to be put in place. These are some of the requirements for an automated deployment:

- A basic requirement is the zero-configuration of end-user equipment. When an end-user receives its modem, only the MAC address and type of service should be needed to have it up and running.
- A desirable requirement is that all equipment outside the backbone can be configured automatically. This becomes very useful when the number of repeaters needed to reach the final clients starts to grow.
- The provider should be able to offer a choice of access packages (several speed levels, with or without VoIP, minimum guaranteed bandwidth, etc…) that fulfills the requirements of any client without the need of personalized configuration. He should be able to offer new packages, modify the properties of a package or move users from one package to another without making the change one by one.

None of these goals can be achieved without a proper provisioning and good logistics. The network design starts with the definition of the hardware configuration of each repeater and HE. Then, each module is to be installed in a specific location. Therefore, there must be a perfect coherence between the type of card, the MAC address and the location where it has to be installed.

The complete network deployment process is explained below:

- The network designer defines the network topology and the type of equipment needed at each location. The information is transmitted to the installers.
- According to the specifications of the operator, the repeaters are configured with the required PLC cards. Information about the MAC addresses of the cards actually installed in the repeater is recorded for network inventory.
- The operator enters the data of the new equipment in the Radius, DHCP and FTP servers.
- The installer installs the repeater at the specified location and turns it on. At this moment the repeater connects to the network and retrieves its configuration parameters for the PLC and the network levels.
- When the repeater is up and running, the network operator tells the service provider that a new zone or building has PLC access.
- The service provider sends the CPE modem to the end-user.
- The MAC of the modem is entered in the database and associated with the service profile requested by the customer.
- The customer powers the modem and gets the configuration to access the network.

The best way to accomplish a deployment with thousands of nodes is using a set of profiles to which nodes are assigned. A profile is a collection of network settings identified by an index number. An example of a profile is shown in figure 3.

```
# VLAN parameters. Only 1 access or a max of 128 trunk
VLAN_TRUNK="1 25 47"

# tag used in voice packets
VLAN_VOICE_ID=1
# prio used in voice packets
VLAN_VOICE_PRIO=5
# tag used in data packets
VLAN_DATA_ID=1
# prio used in data packets
VLAN_DATA_PRIO=0

# Limit Bandwidth facility
# enable limit bandwidth in upstream
LIMIT_BW_UP_ENABLED=yes
# limit bandwidth in upstream in bps
LIMIT_BW_UP=256000
# limit bandwidth in downstream in bps
LIMIT_BW_DOWN=512000
```

Figure 3-2: Example of a Profile File

Using service profiles, the network provider may have one file for each type of service. End-users will be offered one of the pre-configured profiles. When the user registers, its MAC address and the profile index are added to the Radius file. Every time the user's modem boots, it will retrieve the predetermined profile.

3.2 PLC QoS enhancements

3.2.1 Problem Statement

The QoS interface its designed to be manually configured by the network operator. Basically, it works by manually allocating a percentage of the system capacity to one user. This allocation is done statically, so it does not adapt to changes in channel usage (for example, a voice call being started or finished).

In some experiments performed by one of the project partners, VoIP subjective quality decreased when the number of simultaneous voice calls increased too much. The problem was solved when VoIP-optimized QoS was enabled, but this had to be done manually, which was not practical.

It was decided to modify the PLC control software so that QoS was automatically reconfigured when VoIP traffic was detected.

3.2.2 Problem Solution

It was decided to modify the driver so that when traffic that matches a certain rule (src/dst port, TOS field, etc.) is detected, the QoS configuration is changed automatically for the pseudo-interface in which the traffic has been detected.

When that matching traffic stops, a time-out period guarantees that the QoS configuration goes back to the original values.

Both the rule-matching process and the QoS configuration are optimized for VoIP, which is the main application being used today on PLC networks that required QoS.

Figure 3-3 and Figure 3-4 show the difference between the static and dynamic QoS configuration. The structure shown in Figure 3-4 is the one that will be implemented in this first stage of the project.

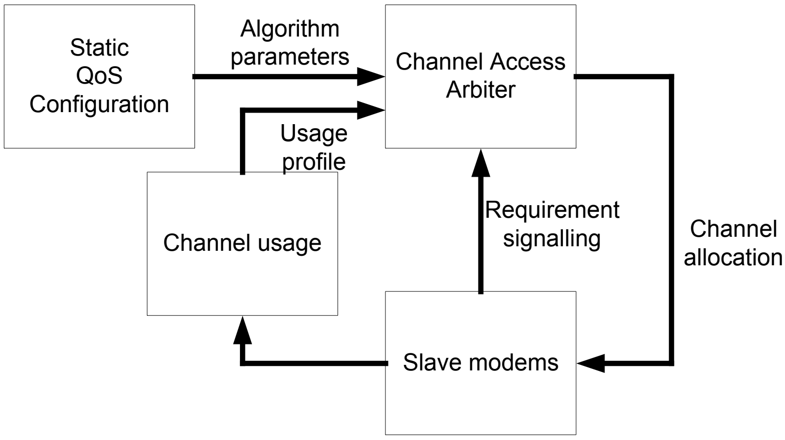

Figure 3-3: Static QoS Configuration

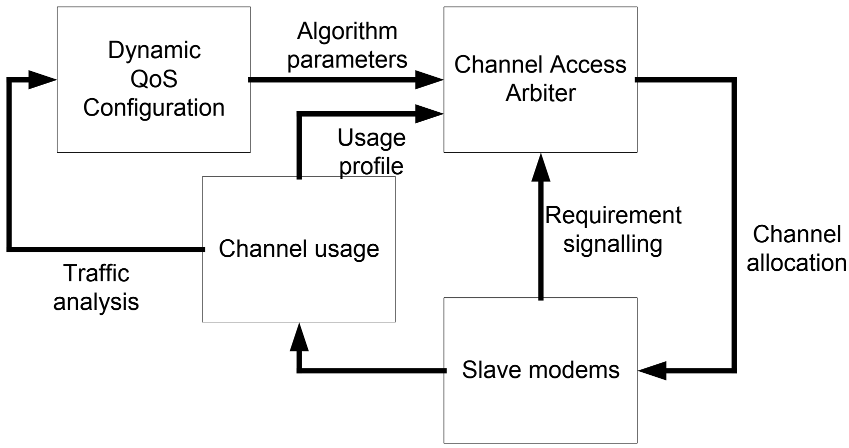

Figure 3-4: Dynamic QoS Configuration

Preliminary implementations of this solution have provided a significant increase in perceived quality for surveyed users.

The model is flexible and programmable, so that it can be adapted to use different fields for identifying VoIP traffic and is valid both for IPv4 and IPv6.

4. SET TOP BOX

4.1 Integration

Integration consisted of three components: The STB, an IPv6 tunnel/router and a stand-alone video server.

4.2 Set Top Box

The Set Top Box (STB) runs Linux using a 2.4.19 kernel. Many of the components in the software stack are not affected by the version of IP that is being used. Technical details describing the implementation of the software stack on the STB are contained in section 2 of document D4.7.

The STB uses static IP addressing. It is assigned both an IPv4 and IPv6 address. The IPv6 address is automatically derived from the MAC address, as defined in the relevant standards.

```
pci12ethaddr = 00:50:94:9b:0a:5c
dnsv6_1 = 2001:800:40:2a03::3
netmask_v6 = 0
netmask1_v6 = 0
gateway_v6 = fe80::240:5ff:fe42:e02c
netaddr = 194.60.92.51
netmask = 255.255.255.192
dns_server1_address = 194.60.92.2
gateway = 0.0.0.0

# ifconfig
eth0      Link encap:Ethernet  HWaddr 00:50:94:9B:0A:5C
          inet addr:194.60.92.51  Bcast:194.60.92.63  Mask:255.255.255.192
          inet6 addr: fe80::250:94ff:fe9b:a5c/64 Scope:Link
        UP BROADCAST RUNNING  MULTICAST  MTU:1500  Metric:1
        RX packets:94269 errors:0 dropped:0 overruns:0 frame:0
        TX packets:11192 errors:0 dropped:0 overruns:0 carrier:0
          collisions:1849 txqueuelen:1000
        RX bytes:121468297 (115.8  MiB)  TX bytes:1688016 (1.6  MiB)
        Interrupt:35

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
        UP LOOPBACK  RUNNING  MTU:16436  Metric:1
        RX packets:645 errors:0 dropped:0 overruns:0 frame:0
        TX packets:645 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
        RX bytes:42834 (41.8  KiB)  TX bytes:42834 (41.8  KiB)

# ip -6 route show
fe80::/64 dev eth0  metric 256
ff00::/8 dev eth0  metric 256
default dev eth0  metric 256
default via fe80::240:5ff:fe42:e02c dev eth0  metric 1024
```

4.3 Router

A router was configured at Pace to allow access to the public IPv6 Internet. This was done via a tunnel over the public IPv4 Internet. The configuration of the router is illustrated below. This is quite complex as the router connects four independent sub-nets via both IPv4 and IPv6. The last entry (gif0) is the IPv6 tunnel through the public IPv4 network.

```
frodo# traceroute6 www.6power.net
traceroute6 to www.6power.net (2001:800:40:2a03::3) from 2001:800:40:2a3a::32, 30 hops max, 12 byte
packets
 1  2001:800:40:2a3a::31  103.198 ms  100.289 ms  128.991 ms
 2  ns1.euro6ix.com  120.621 ms  150.937 ms  112.263 ms
frodo#  ifconfig
fxp0: flags=8a43<UP,BROADCAST,RUNNING,ALLMULTI,SIMPLEX,MULTICAST>  mtu 1500
        inet 194.60.92.2  netmask 0xffffffc0 broadcast 194.60.92.63
        inet6 fe80::203:47ff:fee9:66f%fxp0  prefixlen 64  scopeid 0x1
        inet6 2001:800:40:2a4b:203:47ff:fee9:66f  prefixlen 64
        inet6 2001:800:40:2a4b::  prefixlen 64  anycast
        ether 00:03:47:e9:06:6f
        media: Ethernet  autoselect (100baseTX <full-duplex>)
        status: active
fxp1: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST>  mtu 1500
        inet6 fe80::202:b3ff:fe96:bad2%fxp1  prefixlen 64  scopeid 0x2
        ether 00:02:b3:96:ba:d2
        media: Ethernet  autoselect (none)
        status: no carrier
de0: flags=8a43<UP,BROADCAST,RUNNING,ALLMULTI,SIMPLEX,MULTICAST>  mtu 1500
        inet 194.60.92.65  netmask 0xffffffc0 broadcast 194.60.92.127
        inet6 fe80::240:5ff:fe41:ed83%de0  prefixlen 64  scopeid 0x3
        ether 00:40:05:41:ed:83
        media: Ethernet  autoselect (100baseTX <full-duplex>)
        status: active
de1: flags=8a43<UP,BROADCAST,RUNNING,ALLMULTI,SIMPLEX,MULTICAST>  mtu 1500
        inet 194.60.92.129  netmask 0xffffffc0 broadcast 194.60.92.191
        inet6 fe80::240:5ff:fe41:ed80%de1  prefixlen 64  scopeid 0x4
        ether 00:40:05:41:ed:80
        media: Ethernet  autoselect (100baseTX <full-duplex>)
        status: active
de2: flags=8a43<UP,BROADCAST,RUNNING,ALLMULTI,SIMPLEX,MULTICAST>  mtu 1500
        inet 194.60.92.193  netmask 0xffffffc0 broadcast 194.60.92.255
        inet6 fe80::240:5ff:fe42:e02c%de2  prefixlen 64  scopeid 0x5
        ether 00:40:05:42:e0:2c
        media: Ethernet  autoselect (100baseTX <full-duplex>)
        status: active
faith0: flags=8043<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet6 fe80::203:47ff:fee9:66f%faith0  prefixlen 64  scopeid 0x6
stf0: flags=1<UP>  mtu 1280
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST>  mtu 16384
        inet6 ::1  prefixlen 128
        inet6 fe80::1%lo0  prefixlen 64  scopeid 0x8
        inet 127.0.0.1  netmask 0xff000000
gif0: flags=8051<UP,POINTOPOINT,RUNNING,MULTICAST>  mtu 1280
        tunnel inet 194.60.92.2 --> 213.172.48.138
        inet6 fe80::203:47ff:fee9:66f%gif0  prefixlen 64  scopeid 0x9
        inet6 2001:800:40:2a3a::32  prefixlen 64
```

4.4 Server

The server streams out an MPEG2 transport stream. The transport stream is encapsulated in IPv6 UDP packets. These packets are multicast, to simulate the transmission of TV channels on a real IP TV network.

A server based on FreeBSD 4.7 was configured to send the multicast streams. This release of FreeBSD contains sufficient support for the IPv6 protocol to enable the transmission of multicasted transport streams.

The Multicast Video Blatter Daemon (MVBD) was used to send the streams. This has been modified to support IPv6 addresses. The kernel has been patched to support the higher precision clock requirements of MVBD. The configuration file on the test server uses a single stream:

```
root /home/mpegs;
default interface fxp0;

file bondclip.4mb.m2t {
  rate 4096000;
  multicast address ff05::1;
  enable;
}
```

The server has been configured with both IPv4 and v6 static addresses:

```
fxp0: flags=8843<UP,BROADCAST,RUNNING,SIMPLEX,MULTICAST>  mtu 1500
        inet 194.60.92.50  netmask 0xffffffc0 broadcast 194.60.92.63
        inet6 fe80::2d0:b7ff:fe17:4c0f%fxp0  prefixlen 64  scopeid 0x1
        ether 00:d0:b7:17:4c:0f
        media: Ethernet  autoselect (100baseTX)
        status: active
lo0: flags=8049<UP,LOOPBACK,RUNNING,MULTICAST>  mtu 16384
        inet6 ::1  prefixlen 128
        inet6 fe80::1%lo0  prefixlen 64  scopeid 0x2
        inet 127.0.0.1  netmask 0xff000000
```

4.5 Testing

Testing consisted of three phases:

1. Ping an IPv6 site on the public Internet via an IPv6 tunnel.
2. Access a web site on the public Internet via IPv6.
3. Configure a stand-alone IPv6 network with a multicast video stream. Play the IPv6 multicast video stream on the STB.

4.6 Pinging an IPv6 site

We chose the site: http://www.6power.net.

Ping6 was run on the STB with the following output:

```
# ping6 www.6power.net
PING www.6power.net (2001:800:40:2a03 ::3): 56 data bytes
64 bytes from 2001:800:40:2a03 ::3: icmp6_seq=0 ttl=62 time=169.8 ms
64 bytes from 2001:800:40:2a03 ::3: icmp6_seq=1 ttl=62 time=125.6 ms
64 bytes from 2001:800:40:2a03 ::3: icmp6_seq=2 ttl=62 time=86.2 ms
64 bytes from 2001:800:40:2a03 ::3: icmp6_seq=3 ttl=62 time=127.4 ms

--- www.6power.net ping statistics ---
4 packets transmitted, 4 packets received, 0% packet loss
round-trip min/ avg/max = 86.2/127.2/169.8 ms
```

4.7 Accessing a web site from the STB via IPv6

The web site and router in the previous test were used. The STB uses the Fresco ANT browser. This was set to access http://www.6power.net and it correctly displayed the site on the TV. Ethereal was used to verify that the transfers were using the IPv6 protocol. The trace below shows the DNS lookup from the STB (00:50:94 is the Pace assigned block of MAC addresses).

```
No.    Time        Source                Destination          Protocol Info
   203 11.796638   2001:800:40:2a4b    :250:94ff:fe9b:a5c 2001:800:40:2a03::3   DNS      Standard query
AAAA www.6power.net

Frame 203 (94 bytes on wire, 94 bytes captured)
   Arrival Time:    Nov  5, 2004 10:33:50.465227000
   Time delta from previous packet: 0.004187000 seconds
   Time since reference or first frame: 11.796638000 seconds
   Frame Number: 203
   Packet Length: 94 bytes
   Capture Length: 94 bytes
Ethernet II,  Src: 00:50:94:9b:0a :5c,  Dst: 00:03:47:e9:06:6f
   Destination: 00:03:47:e9:06:6f (Intel_e9:06:6f)
   Source: 00:50:94:9b:0a   :5c (194.60.92.51)
   Type: IPv6 (0x86dd)
Internet Protocol Version 6
   Version: 6
   Traffic class: 0x00
     Flowlabel: 0x00000
   Payload length: 40
   Next header: UDP (0x11)
   Hop limit: 64
   Source address: 2001:800:40:2a4b   :250:94ff:fe9b:a5c
   Destination address: 2001:800:40:2a03   ::3
User Datagram Protocol,   Src Port: 1025 (1025),   Dst Port: domain (53)
   Source port: 1025 (1025)
   Destination port: domain (53)
   Length: 40
   Checksum: 0xeb87 (correct)
Domain Name System (query)
   Transaction ID: 0x0c45
   Flags: 0x0100 (Standard query)
         0... .... .... .... = Response: Message is a query
      .000 0     ... .... .... =   Opcode: Standard query (0)
         .... ..0. .... .... = Truncated: Message is not truncated
      .... ...     1 .... .... = Recursion desired: Do query recursively
         .... .... .0 .. .... = Z: reserved (0)
         .... .... ...0 .... = Non-authenticated data OK: Non-authenticated data is unacceptable
   Questions: 1
   Answer    RRs: 0
```

```
    Authority    RRs: 0
    Additional    RRs: 0
    Queries
            www.6power.net: type AAAA, class   inet
            Name: www.6power.net
            Type: IPv6 address
            Class:        inet

No.     Time        Source                Destination           Protocol Info
    204 11.911797   2001:800:40:2a03    ::3   2001:800:40:2a4b:250:94ff:fe9b:a5c DNS      Standard query
response AAAA 2001:800:40:2a03::3

Frame 204 (286 bytes on wire, 286 bytes captured)
    Arrival Time:    Nov  5, 2004 10:33:50.580386000
    Time delta from previous packet: 0.115159000 seconds
    Time since reference or first frame: 11.911797000 seconds
    Frame Number: 204
    Packet Length: 286 bytes
    Capture Length: 286 bytes
Ethernet II,  Src: 00:03:47:e9:06:6f,  Dst: 00:50:94:9b:0a :5c
    Destination: 00:50:94:9b:0a   :5c (194.60.92.51)
    Source: 00:03:47:e9:06:6f (Intel_e9:06:6f)
    Type: IPv6 (0x86dd)
Internet Protocol Version 6
    Version: 6
    Traffic class: 0x00
      Flowlabel: 0x00000
    Payload length: 232
    Next header: UDP (0x11)
    Hop limit: 62
    Source address: 2001:800:40:2a03    ::3
    Destination address: 2001:800:40:2a4b    :250:94ff:fe9b:a5c
User Datagram Protocol,   Src Port: domain (53),   Dst Port: 1025 (1025)
    Source port: domain (53)
    Destination port: 1025 (1025)
    Length: 232
    Checksum: 0xb7f0 (correct)
Domain Name System (response)
    Transaction ID: 0x0c45
    Flags: 0x8580 (Standard query response, No error)
            1... .... .... .... = Response: Message is a response
        .000 0     ... .... .... =   Opcode: Standard query (0)
        .... .1     .. .... .... = Authoritative: Server is an authority for domain
            .... ..0. .... .... = Truncated: Message is not truncated
        .... ...     1 .... .... = Recursion desired: Do query recursively
            .... .... 1... .... = Recursion available: Server can do recursive queries
            .... .... .0 .. .... = Z: reserved (0)
            .... .... .. 0. .... = Answer authenticated: Answer/authority portion was not authenticated by the server
            .... .... .... 0000 = Reply code: No error (0)
    Questions: 1
    Answer    RRs: 1
    Authority    RRs: 3
    Additional    RRs: 4
    Queries
            www.6power.net: type AAAA, class   inet
            Name: www.6power.net
            Type: IPv6 address
            Class:        inet
    Answers
            www.6power.net: type AAAA, class   inet,  addr 2001:800:40:2a03::3
            Name: www.6power.net
            Type: IPv6 address
```

```
        Class:      inet
        Time to live: 2 days
        Data length: 16
            Addr: 2001:800:40:2a03::3
  Authoritative   nameservers
     6power.net: type NS, class      inet,  ns dns1.novagnet.com
        Name: 6power.net
        Type: Authoritative name server
        Class:      inet
        Time to live: 2 days
        Data length: 19
        Name server: dns1.novagnet.com
     6power.net: type NS, class      inet,  ns dns1.consulintel.com
        Name: 6power.net
        Type: Authoritative name server
        Class:      inet
        Time to live: 2 days
        Data length: 19
        Name server: dns1.consulintel.com
     6power.net: type NS, class      inet,  ns ns1.euro6ix.com
        Name: 6power.net
        Type: Authoritative name server
        Class:      inet
        Time to live: 2 days
        Data length: 14
        Name server: ns1.euro6ix.com
  Additional records
        ns1.euro6ix.com: type A, class   inet,  addr 213.172.48.141
        Name: ns1.euro6ix.com
        Type: Host address
        Class:      inet
        Time to live: 2 days
        Data length: 4
            Addr: 213.172.48.141
        ns1.euro6ix.com: type AAAA, class   inet,  addr 2001:800:40:2a03::3
        Name: ns1.euro6ix.com
        Type: IPv6 address
        Class:      inet
        Time to live: 2 days
        Data length: 16
            Addr: 2001:800:40:2a03::3
        dns1.novagnet.com: type A, class   inet,  addr 213.172.48.139
        Name: dns1.novagnet.com
        Type: Host address
        Class:      inet
        Time to live: 1 hour
        Data length: 4
            Addr: 213.172.48.139
        dns1.consulintel.com: type A, class   inet,  addr 217.126.187.160
        Name: dns1.consulintel.com
        Type: Host address
        Class:      inet
        Time to live: 2 days
        Data length: 4
            Addr: 217.126.187.160
```

4.8 Playing IPv6 multicast video

Following this, the stand-alone server was configured as described above. The STB settings remained the same as for the previous two tests. The STB browser was pointed at a multicast test page that used Java Script to command the media stack on the STB to play multicast video.

Ethereal was used to monitor the traffic and verify that the packets were valid IPv6. A dump of one of these packets is presented below:

```
No.     Time        Source                 Destination           Protocol Info
   1227 3.135857    fe80    ::2d0:b7ff:fe17:4c0f ff05::1              UDP      Source port: 1041  Destination port:
55555

Frame 1227 (1378 bytes on wire, 1378 bytes captured)
    Arrival Time:    Nov  5, 2004 11:07:19.582748000
    Time delta from previous packet: 0.005774000 seconds
    Time since reference or first frame: 3.135857000 seconds
    Frame Number: 1227
    Packet Length: 1378 bytes
    Capture Length: 1378 bytes
Ethernet II,  Src: 00:d0:b7 :17:4c:0f,  Dst: 33:33:00:00:00:01
    Destination: 33:33:00:00:00:01 (IPv6-Neighbor-Discovery_00:00:00:01)
    Source: 00:d0:b7   :17:4c:0f (Intel_17:4c:0f)
    Type: IPv6 (0x86dd)
Internet Protocol Version 6
    Version: 6
    Traffic class: 0x00
      Flowlabel: 0x00000
    Payload length: 1324
    Next header: UDP (0x11)
    Hop limit: 5
    Source address: fe80    ::2d0:b7ff:fe17:4c0f
    Destination address: ff05   ::1
User Datagram Protocol,   Src Port: 1041 (1041),   Dst Port: 55555 (55555)
    Source port: 1041 (1041)
    Destination port: 55555 (55555)
    Length: 1324
    Checksum: 0x4702 (correct)
Data (1316 bytes)

0000  47 00 32 1b 00     ce 35 97 80 56 1e b5 46 5c 00       00   G.2...5..V  ..F\..
0010  01 17 22 10     fe b0 63 00 12 04 a6 37 00 d4 03 95   .."...        c....7....
0020  d0 c3 88 a7 38 91 76 20 f1 21 60 2c bb 67 90 43   ....8.v .!`            ,.g.C
0030  b7 52 a7 65 ad f1 11 b3 70 b1        fe 01 7c 02 22 36   .    R.e....p...|."6
0040  58 1b 17 44 54 89 d9 99 f0 07 f4 44 41 1b          bc 90   X..DT  ......DA...
0050  e3 85 90 21 40 41 c3 e2 f1 18 50 11 3c 3a 00           fa   ...!@A....P.<:..
0060  e8 6c a1 98 71 04 88      da 38 e2 30 0d 65 8e 06 2f   .      l..q...8.0.e../
0070  ff a7 1c 45 37 d7 bb 1a a8 49 21 d4 0b 7f ff 0d   ...E7....I!.....
0080  5b 8a 22 c4 50 3b 00 75 54 43 a2 c2 26 25          ce 5f   [.".  P;.uTC..&%._
0090  62 71 3c e9 db     ba 88 81 20 6b c9 3f 23 ac 9c 01          bq<.....  k.?#...
00a0  c5 2c d1 6c d9 d4 34 e5 89 65 91 e9         da 7b d9 d0   .,.l..4   ..e...{..
00b0  93 0f 20 b0 10 de 58      58 74 93 80 36 47 00 32 1c   .. ...XXt       ..6G.2.
00c0  0f 3b 10 6d 8c 5e     ab f4 51 8b 86 0a 60 f0 17 9f   .;.       m.^..Q...`...
00d0  64 40 23 11 4f c2 40 e8 f8 06 61 74 44 f5 02 e7             d@#.O.@...atD...
00e0  ff c0 d8 00 30 e1 70 f0 5d 00 19 74 43 f4 0e 01   ....0.p.]..           tC...
```

00f0 f0 f8 ee 70 f3 58 17 00 06 0a 05 cf ff b5 b8 e3 ... p.X..........
0100 c2 c2 87 2e 7a 22 79 80 1e 9b 7f 11 21 d2 70 72 .... z"y.....!.pr
0110 c9 f0 10 97 44 5a 3b d3 da 34 54 60 b7 a2 1a 09 ....DZ;..4T`....
0120 a0 cf f1 ea c0 1f 01 e5 be 38 e3 e3 82 87 c9 5b ....8.....[
0130 32 9d 47 38 ee ce c2 96 ab 49 c7 ad 66 ea 22 3e 2.G8..... I..f.">
0140 1f a7 e6 87 8e b5 03 00 00 80 fe 8d 16 61 f1 ec ....a..
0150 09 df fc e0 2d bb a1 aa 1e b3 14 16 14 ec 01 bc ....-...........
0160 01 c3 28 2d 8c 20 4c 03 53 5d 85 18 c2 67 fc 60 ..(-. L.S]...g .`
0170 0c c3 96 6d 10 d0 e6 25 47 00 32 1d dc e3 89 cb ...m...%G.2.....
0180 1d 1c 16 38 dc c4 e2 3d 9b 8f 73 f8 8f ba 8d 57 ...8...=.. s....W
0190 0f 27 44 96 e3 8f 5f 34 57 c1 52 e7 bb 1d 40 2a .'D..._4W.R ...@*
01a0 ef 9d 82 80 3e 18 75 0d 67 50 70 1a 52 86 92 54 ....>. u.gPp.R..T
01b0 3f e6 99 2a 53 81 cc 6a 87 97 c4 8e 92 03 30 0d ?..* S..j......0.
01c0 e3 2e 83 ec 93 e7 11 3d 98 29 c7 2f b3 9f be 14 ....=.)./....
01d0 1c 47 80 5e 46 22 18 22 48 4f 74 01 3e 35 0c 24 . G.^F"."HOt.>5.$
01e0 20 42 b7 16 1d 44 46 0a a0 1c f0 0e 48 f0 11 88 B...DF.....H...
01f0 b7 80 39 05 ef ff a2 2a 0c d7 73 80 7f 28 d0 5c .. 9....*..s..(.\
0200 00 18 70 2f 80 0d c9 b2 e2 7c 1c 3f fe 32 56 01 .. p/.....|.?.2V.
0210 73 02 e0 00 c0 1d c0 00 00 01 18 2a fd 22 51 0d s..........*."Q.
0220 86 98 6b aa dd 8f 20 87 85 47 2c f0 60 00 19 22 .. k... ..G ,.`.."
0230 81 a0 00 4c 47 00 32 1e a2 22 0b a1 e0 be 00 31 ...LG.2.." 1
0240 14 e1 64 7f 87 2b 5f 18 c6 e0 5c ff fb 34 ee 7e ..d ..+_...\..4.~
0250 00 e2 f6 d0 75 06 0f 1e 03 f8 d0 4f 00 28 b0 f1 ....u......O.(..
0260 1a 4a ba 96 38 f6 84 d3 f9 8c 6c e0 be 00 2c 28 .J..8 .....l...,(
0270 3e 23 05 01 1b 37 93 cf 20 8b 23 5d 06 6a f6 87 >#...7.. .#].j..
0280 b8 1c 85 8e 0b 11 6c 24 03 9d 44 56 2c 23 e5 f2 ...... l$..DV,#..
0290 26 62 02 a2 78 04 43 63 21 00 be 00 34 44 a1 f0 & b..x.Cc!...4D..
02a0 e3 49 03 9b 1e 26 01 f4 06 b3 fb 06 9f ff bf 41 .I...&.........A
02b0 ec 60 70 07 51 80 2c 88 d7 f4 0f 20 c4 f0 72 00 .` p.Q.,.... .. r.
02c0 18 f0 1f 07 cd 57 f6 87 01 b1 33 38 b8 1b 00 06 ..... W....38....
02d0 e8 30 83 1d 20 1c c8 c6 c9 cb 37 c4 e2 3d 10 d8 .0.. .....7..=..
02e0 b1 e1 6a 63 b0 34 ff fc 5b 0d 57 56 51 a0 40 55 ..jc.4 ..[.WVQ.@U
02f0 47 00 32 1f e1 e7 0f ea 27 87 87 e3 a2 d1 d5 d6 G.2.....' ....
0300 29 c6 39 c4 72 01 f4 44 69 b4 91 e6 47 10 44 45).9.r..Di...G.DE
0310 f3 01 2f ff 96 1c 06 af 38 ee 3c 8c 20 75 08 69 ../ .....8.<. u.i
0320 b6 a1 87 8f ea 3c d7 3d 84 01 18 62 cf e2 05 0b ..... <.=...b....
0330 23 1e 3c d8 ed 97 f8 80 5d 00 1a 46 38 f5 6c 1c #.<.....]..F8.l.
0340 27 0f 1c bb ae 49 5a 50 a2 42 94 69 ce fc 38 0d '....IZP.B.i..8.
0350 35 16 48 3d 63 87 38 0c a2 f7 52 54 91 86 e2 00 5.H=c.8...RT....
0360 e1 fc 7c 18 a4 f1 b9 d9 cd 10 fa 6e 7d 08 8c 18 ..| ....n}...
0370 41 58 55 32 47 8b c8 15 fe e3 38 f1 4a e2 a3 54 AXU2G.....8.J..T
0380 46 5f 2d c8 1d 60 96 00 46 c0 38 60 12 67 cd ce F_-..` ..F.8`.g..
0390 3c d1 47 07 1b 74 43 30 bd 0e 43 ec 5a 78 cc b1 <.G.. tC0..C.Zx..
03a0 ca 61 4b ce e3 33 9e 11 95 78 07 e4 47 00 32 10 .aK..3...x ..G.2.
03b0 5d 6c 07 96 6e ef b2 92 07 b8 47 0e 1a 3c c6 54] l..n.....G..<.T
03c0 70 30 80 0d ed a2 71 0c 3b 91 98 58 0b a2 43 63 p0.... q.;..X..Cc
03d0 b6 c6 05 0e 1d 80 d5 a0 93 c5 e1 4e 4e 34 2c e0 ....NN4,.
03e0 f8 34 0d 81 e0 a5 78 81 44 46 17 69 17 03 38 00 .4....x.DF.i..8.
03f0 aa c5 13 c9 c3 c8 12 5b 38 07 47 de ed 5e 01 cc ....[8.G..^ ..
0400 38 03 f7 1c 01 b4 95 8b 65 8e f1 ae 29 9d 66 8e 8.......e...).f.
0410 b9 41 37 48 f1 42 80 88 83 0e 8c 61 c4 65 de 50 .A7H.B..... a.e.P
0420 a1 3c 70 0b ec 9d 00 00 00 01 19 22 21 d8 b9 d2 .<p........"!...
0430 40 0e 02 04 68 e0 19 9b 6a c4 60 22 af 0b f8 03 @...h...j.`"....
0440 d0 21 76 15 ab c0 d0 e7 03 46 c9 f8 4a c0 64 06 .! v......F..J.d.
0450 ac d0 1f 8f 5d b0 06 c0 1f 5e ea 0c a3 cd f7 3c ....] ....^.....<
0460 2d cc 3c d9 5d c7 af 80 47 00 32 31 43 00 ff ff -.<.]...G.21C...
0470 ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ....
0480 ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ....
0490 ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ....
04a0 ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ff ....
04b0 7e 38 0e 4a 6e ee 1e 34 e3 c0 56 e2 f0 f9 58 77 ~8.Jn..4 ..V...Xw
04c0 30 de 41 16 38 ea a2 25 16 5d fb 09 0b 20 81 18 0.A.8..%.] ... ..

```
04d0  28 8a 20 48 0d 65 13 cc c1 f6 c8 6c 47 1c 78        ab   (.   H.e.....lG.x.
04e0  a1 45 1e 04 4d 92 38      fd 1c 1e a3 16 15 0d 39 7b   .E..M.8      .......9{
04f0  81   ba e9 2b c9 e0 74 7d     ec 3c 50 80 1a 09 8b 30   ...+..t}      .<P....0
0500  79 e3 95 25 5c 63 8b 6c e7 39 10 c2 0d d1 16        cb   y..%\  c.l.9......
0510  08 f5 0e 80 5c b5 b0      bc 2c c8 92 6b 6e 69 10 c9   ....\...,..      kni..
0520  82 00 8b 88                                           ....
```

5. SUMMARY AND CONCLUSIONS

This document provides full technical details on network functions developed during the 6POWER project, focusing on the high interaction between them, including IPv6 autoconfiguration, DNS, Radius, Routing, and QoS.

Furthermore describes the upgrade of the STB to fully support IPv6 and multicast.

Several enhancements have been introduced in all the devices (Head End, Home Gateway, CPE and Set-Top-Box), which are very relevant for the reduced cost of the operation and management of IPv6-enabled PLC networks.

6. REFERENCES

RFC2462 IPv6 Stateless Address Autoconfiguration

RFC2474 Definition of the Differentiated Services Field (DS Field)

RFC2865 Remote Authentication Dial In User Service (RADIUS)

RFC3315 Dynamic Host Configuration Protocol for IPv6 (DHCPv6)

RFC3646 DNS Configuration Options for DHCPv6

RFC3633 IPv6 Prefix Options for DHCPv6