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Dynamic IP configuration of terminals in broadcasting networks

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Abstract

The concept of synergy between broadcasting and telecommunication networks has been strengthened by the emergence of multi-modal terminals, which are used in a broadcast environment (mainly in DTV-Digital Television networks) to provide IP-based multimedia services. The migration of IPv4/IPv6 applications, either interactive or not, in a broadcasting network, requires that certain parameters, such as Host, Gateway and DNS IP addresses are configured in the terminals, either statically or dynamically. This paper discusses issues of dynamic configuration of IP parameters for DTV terminals, based on an overview of relevant mechanisms usually used in access networks. It proposes an IP-based auto-configuration protocol tailored to the needs of an IP/DTV access platform, describes its implementation and evaluates its behaviour in a laboratory-based DVB-T network.

Keywords: IP-over-DTV; Interactive broadcasting; Dynamic configuration

1. Introduction

The worldwide tendency for global convergence of networks and services has resulted in the transformation of digital broadcast networks, from mere carriers of unidirectional media streams to broadband access networks for integrated, all-IP services. Contemporary digital television (DTV) networks, as successors to analog TV systems, are being used as access networks for IP-based services, either interactive or not. The common digital baseband format, namely the MPEG-2 Transport Stream, previously used only for the transport of encoded audio/visual streams, has extended its functionality to support all types of digital information, including IP data ("Datacasting"). The adoption of adaptation protocols such as multi-protocol encapsulation [1] and unidirectional lightweight encapsulation [2] for the insertion of IP data into the MPEG-2 TS, has greatly contributed to the migration of native IPv4/IPv6 applications to the world of digital broadcasting, both satellite and terrestrial.

The use of broadcasting terminals for accessing IP services requires that they incorporate an IPv4/IPv6 protocol stack. For the proper operation of the latter, it is essential that certain parameters have to be

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configured, such as IPv4/IPv6 host, gateway and DNS addresses. These parameters have been until now set in a static manner, a rational approach if one considers that IP/DTV service provision is mainly restricted to the satellite access domain (e.g., via DVB-S/DVB-RCS platforms), where fixed terminals almost never require re-configuration. Nevertheless, with the emergence of terrestrial digital television infrastructures, where mobile use from portable terminals aiming at ubiquitous access is anticipated [3], a dynamic/automatic mechanism IP configuration is essential. In this context, this paper discusses the issue of dynamic IP set-up of interactive DTV/IP terminals. It shows why widely used mechanisms like DHCP are inadequate due to the special features of digital television networks, and proposes and implements an IP-based protocol approach.

The article proceeds as follows: Section 2 presents a general topology of IP/DTV networks and divides them into three rough categories, outlining the configuration needs of each case. Section 3 discusses the requirements that an IP auto-configuration mechanism should fulfil in a DTV network and investigates whether existing solutions, such as DHCP, could be used. Section 4 proposes a novel approach for an IP-based dynamic configuration protocol, describing its functionality and suggesting a state diagram. Section 5 presents the implementation of the protocol into platform-independent Java modules and evaluates its behaviour in a laboratory-based interactive DVB-T set-up. Finally, Section 6 concludes the paper.

2. IP-over-DTV access scenarios

For simplicity reasons, in this article, the term "Digital Television Network" is assumed to refer to a single DTV downlink conveying a single MPEG-2 TS to a certain coverage area (e.g., a satellite footprint). However, the modelling and the mechanisms described in this paper can be easily expanded to include multi-bouquet, multi-transmitter infrastructures.

At the broadcaster's site, an IP-to-DTV encapsulator is used to insert IPv4/IPv6 traffic in the MPEG-2 Transport Stream. On the other side, the terminal, following demodulation, decoding and demultiplexing, decapsulates the datacast streams and feeds them to its IP stack for processing. Since the digital broadcast channel is unidirectional, the support for fully interactive services requires the presence of an interaction channel [4]. The existence and nature of the latter is crucial to the IP configuration process and, in this context, the DTV network topologies can be categorised

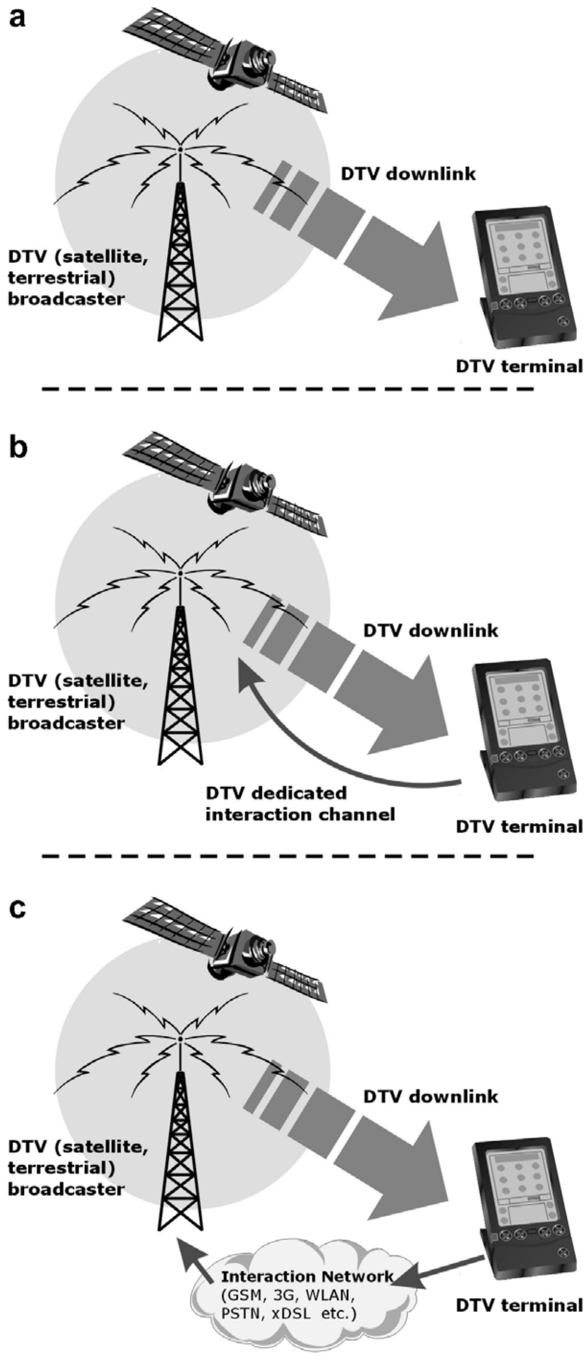

Fig. 1. IP/DTV access scenarios depending on the type of return channel: (a) unidirectional, (b) bi-directional with native DTV interactivity and (c) hybrid bi-directional with an external interaction network.

into three discrete generalised architectures (see Fig. 1).

2.1. Unidirectional topology

This case is the most usual nowadays and includes all broadcast-only platforms, satellite or terrestrial, where no return link (from the terminal back to the broadcaster) exists. The terminals operate in a receive-only mode and receive DTV programs multiplexed with datacast IP data. Data services are not fully interactive, they can only provide pseudo-interactivity by means of off-line local access. In this case, the terminals have no way to interact with a network entity at the broadcaster's side to request configuration information. The latter can only be "pushed" to all receivers. DNS and gateway addresses are of no use, and a common IP host address can be assigned to all terminals for functionality reasons only. Since the DTV receivers cannot send data, this common address does not raise any conflict issues.

2.2. Bi-directional topology with native DTV interactivity

In this case, the terminals support full interactivity by utilising a unidirectional interaction (return) channel that has been specially developed to integrate with DTV networks, such as DVB-RCS (Return Channel via Satellite) or DVB-RCT (Return Channel-Terrestrial). Unlike the previous scenario, it is essential in this case that the terminals' IP parameters are fully configured and their host addresses are unique. Until now, native DTV interactive solutions [5] are commonly based on the static configuration approach, i.e., the terminal comes pre-configured by the installer/service provider. This solution is satisfactory for certain cases, e.g., where a satellite terminal is fixed (no handovers) and bound to a single service provider. However, for moving terrestrial or satellite transceivers performing handovers or in cases that multiple service providers are to be supported, a dynamic solution is essential. It is possible, for instance, that channel zapping in a terrestrial receiver could correspond to switching among different broadcasters/service providers. In order that the receiver's settings are set to the IP address space of each provider, an IP configuration procedure could need to be activated after each zap.

2.3. Bi-directional topology with an external interaction network

This scenario corresponds to a hybrid interactive topology [6] where the DTV broadcast channel is used for forward datacasting, and a foreign IP network is utilized to support interaction. The latter can be any wired or wireless IP-enabled infrastructure, such as GPRS/3G, WLAN, PSTN or xDSL. The terminal is equipped with a dual-interface front end: one for the broadcast network (i.e., a DTV receiver) and one for the interaction channel (e.g., a 3G modem or a WLAN interface). In this scenario, the interface bound to the interaction network receives the IP configuration from its own infrastructure via a standardized mechanism anyway (e.g., via DHCP for a WLAN interface). However, if the broadcaster is to provide interactive services, it is essential that the DTV receiver module must also be configured. Otherwise, the broadcaster will have to deal with a large pool of heterogeneous IP addresses, different according to the interaction network provider used by each client, and handling of interaction data will be rather complicated. So, an IP/DTV dynamic configuration mechanism is also required in this case.

3. Requirements for an IP/DTV dynamic configuration protocol

DHCP (Dynamic Host Configuration Protocol) [7], and DHCPv6 [8] are the most common IETF-standardized protocols for dynamic configuration of host IPv4 and IPv6 parameters, respectively. These protocols are used in a huge spectrum of IP-enabled networks.

DHCP works on a client/server basis. Upon the connection of a new host to a certain sub-network, the unconfigured host (client) broadcasts a "server discovery" (DHCPDISCOVER) message using a network- and link-level broadcast address. The DHCP Server, normally unique within a subnet, responds with a unicast DHCPOFFER message, containing the IP configuration parameters and a lease period. The client responds with a DHCPREQUEST back to the server, requesting the offered parameters, and the four-way handshake process ends with the transmission of DHCPACK from the Server to the Client, confirming that the client has been associated with the new parameters. The operation of DHCPv6 is quite similar, with added support for IPv6 and exploitation of its new features.

Unfortunately, IP/DTV networks, due to their particular nature, have certain requirements that cannot be satisfied by the DHCP/DHCPv6 protocol "as-is". The most important ones are:

- *Support of all three generic topologies* described in (II) via a unified approach.
- *IP-unicast-only requests.* Due to the heterogeneity of a composite interactive DTV network, there is no common link-layer over which requests and responses could be broadcast. The communication from the terminal to the broadcaster should be entirely based on unicast IP and should be independent from any underlying link technologies.
- *Scalability.* Unlike a LAN or even a cellular network, a DTV platform should be capable of accommodating even hundreds of thousands of users. The proposed mechanism must be scalable enough to support a large pool of end users.
- *Simultaneous IPv4 and IPv6 support.* The parameters, which are dynamically configured, should correspond to both versions of the Internet Protocol. This means, e.g., that the client terminal is assigned at the same time both a v4 and a v6 global unicast host address via the same protocol. Stateless IPv6 auto-configuration also has to be supported.
- *Authenticated access.* Since, unlike a wired LAN, a broadcast network is "open" to anyone, security from unauthorised requests is a major issue. The usage of a standardized authentication method such as the one described in [9] can be considered.
- *Utilisation of native DTV signalling* so that broadcast configuration data can be located in the broadcast MPEG-2 TS.
- *Relatively low complexity*, so that (i) the protocol can be implemented even in handheld terminals and (ii) the computational cost at the broadcaster due to the large number of request processes can be minimised. There are many options of DHCP, such as Relaying and Solicitation, which are of no use in either of the aforementioned scenarios.
- *Easy and modular implementation* on existing satellite/terrestrial/handheld digital television terminals without modifications in their hardware or their lower layers (demultiplexing/decapsulation modules).

It is obvious that the DHCP protocols, which exist and are used in networks with a common link-layer (e.g., in an Ethernet or a WLAN) cannot be used "as-is" in our case, where the communication between the terminal and the configuration server cannot be established in a link-layer basis, since they do not belong to a common link. This holds especially in the case where the interaction channel is implemented by an external IP network. A new mechanism needs to be introduced, based on the philosophy of existing dynamic configuration protocols, but implemented under a different perspective.

4. A proposed IP-based dynamic configuration mechanism

The paper proposes an IP-based mechanism for dynamic configuration of the digital broadcasting terminals, which fulfills all the requirements stated in the previous section. For reference reasons, this mechanism/protocol will be referred to as IDDCP (IP-over-DTV Dynamic Configuration Protocol). This section presents the principles of operation, the message types, the algorithm and the state diagram of the IDDCP protocol. The philosophy followed and the message types are mainly derived from the operation of DHCPv4/DHCPv6. Nevertheless, many adaptations have been introduced to match the requirements described in the previous section.

The approach is based on a client–server model, where all IDDCP messages are conveyed over UDP/IP, either over the broadcast channel or the interaction network. The IP-based model allows for easy, IP-level implementation on any existing terrestrial or satellite DTV terminal, without any modification in its RF/demultiplexing/decapsulation stack. The "Client" is considered to be the DTV terminal whose parameters are to be set, and the "Server" is a separate entity located in the broadcaster's premises. The role of the IDDCP Server will be the management and allocation of IP parameters to terminals. Since the number of Clients can be in the order of tens or thousands, it would be convenient to use an open database (e.g., SQL-based) to store the assigned parameters rather than an internal table, as most DHCP Servers do. Regarding the UDP ports used, the numbers used by DHCPv6 could be adopted: 546 for the Client and 547 for the Server.

The message types, which are required are:

- *ADVERTISE:* It is broadcast at regular intervals by the Server to all Clients over the DTV channel and contains its own IPv4/IPv6 global address

(or multiple addresses if multiple Servers exist), a subnet prefix/mask for all Clients and a common temporary IP address, which is used by all Clients during the configuration procedure.
- *REQUEST:* It is sent by the Client to the Server over the interaction channel to request configuration parameters. It contains the MAC address of the DTV interface and a UID (Unique Identifier), similar to DHCPv6's DUID, which is used by the Server to uniquely identify Clients.
- *REPLY:* It is sent by the Server via the broadcast channel as a response to a REQUEST command. It contains a set of configuration parameters: IPv4 and IPv6 addresses of the network Gateway, the DNS Server and of course of the Client terminal itself. It also contains a "lease" value, i.e., a time duration after which the parameters assigned are invalid and they need to be renewed via a RENEW message (see below).
- *CONFIRM:* It is sent by the Client to the Server as a confirmation that the REPLY message has been promptly received and accepted.
- *RENEW:* It is sent by the Client upon the expiration of the lease timer, as a request to the Server in order to renew the assigned parameters.
- *RECONFIGURE:* It is sent by the Server to the Client if any of the parameters assigned need to be changed. Upon reception of RECONFIGURE, the Client has to re-initiate the dynamic configuration process.

For simplicity reasons, it is assumed that, for a first approach, neither the Client's request nor the Server's offer can be declined. If this is so (an unlikely case), then the appropriate message types will have to be added.

The state diagram of the proposed mechanism, from the Client side, is depicted in Fig. 2. The Server-side diagram can be directly derived, and is thus omitted.

IDDCP is based on a four-way handshake. Its operation is described as follows:

At first, a Client, which needs to be configured (e.g., after power-up, after a handover, or when IP services are activated) listens to the broadcast stream to locate a Server ADVERTISE message. In general, it would be convenient that a dedicated DTV AC (AutoConfiguration) Program Number (corresponding to a certain AC PID) is devoted to the transport of IDDCP messages. This Program Number can be declared via native DTV signalling. For example, in the case of DVB networks, the standardised INT (IP/MAC Notification Table) [1] can be used, where the IDDCP Program can be declared as having a target_IP of 255.255.255.255 and a target_MAC of 0xff:ff:ff:ff:ff:ff (broadcast) so that it is processed by all terminals. ADVERTISE will be contained in a UDP packet, having the broadcast IP address in its "destination" field.

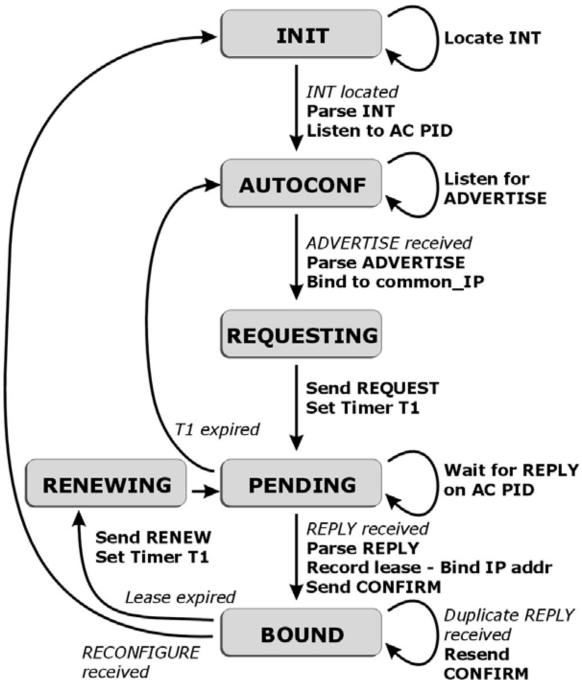

Fig. 2. IDDCP state diagram (Client).

By parsing ADVERTISE, the Client specifies the Server's IP, the subnet prefix/mask and assigns to the DTV interface a common_IP address, which is temporary and is the same for all configuring terminals. In the unidirectional case with "receive-only" terminals, this common_IP is sufficient as described in Section 2 and the process ends here. In the case of IPv6, stateless auto-configuration can take place, using the advertised prefix.

In the case that a return channel exists (cases (b) and (c) of Section 2), this temporary address is used by the Client to form the REQUEST message, which will also contain its own MAC address and a globally unique UID. The latter can be locally generated as described in [8]. These two values, the MAC address and the UID are used to uniquely identify the terminal throughout the entire IDDCP process. Upon sending REQUEST, the Client initialises and starts a timer. If the timer expires and no reply is received, it is assumed that the message was lost and it is re-sent.

The Client listens to the AC Program and waits for a REPLY message from the Server. REPLY is sent also with a broadcast "destination IP" address, since the Client parameters are not yet set. Among the messages carried in the program, the Client can locate its own REPLY by matching the UID found in the body of the message with its own. It is recommended that for security reasons, REPLY messages do not contain the MAC addresses of the Client. If this were done, an eavesdropper could easily record the addresses of all configured Clients, and could possibly use them to generate unauthorised REQUESTs. When received, the REPLY will contain all necessary information, as aforementioned, and the Client uses them to configure itself.

When configuration is complete, the Client will respond with a CONFIRM message, now using its new IP address. If a duplicate REPLY is received, it is assumed that CONFIRM was lost and it is re-sent. At the same time, a lease timer is initialised, as declared in REPLY. The configuration is considered valid until the lease expires. When this happens, the Client will have to send a RENEW message to the Server and receive another REPLY with the same or updated configuration information.

Finally, the Server will have the option of sending a (unicast or broadcast) RECONFIGURE message to the Client(s), to force them to re-initiate the dynamic configuration process before the lease expires.

After the completion of the process, the Client is in the BOUND state, and the IP parameters of its DTV interface are properly set. The terminal has now been enabled for interactive IP-based DTV services.

The aforementioned procedure is an initial proposed approach to the required dynamic configuration protocol and can be further enhanced to support additional functionality, such as authentication and security. However, it has to be kept at relatively low complexity so that it can be easily implemented even in handheld terminals and so that computational demands on the Server are kept at reasonable levels.

5. Implementation and evaluation

In order to validate the proposed configuration mechanism, a laboratory-based, yet fully functional testbed was implemented, as depicted in Fig. 3.

The architecture is based on DVB-T as broadcast platform, and on a WiFi network providing the uplink (return channel). The DVB-T chain (IP-to-DVB Encapsulator, Multiplexer, Modulator) is based on commercial modules, and a low-power RF amplifier is used for indoor transmission of the DVB-T signal. The return channel is realised by a WiFi access point feeding the provider's LAN with the user requests via a router-network emulator. The latter runs the NISTNet [10] network emulator to yield pre-defined amounts of delay, jitter and packet loss on the uplink. The wireless user

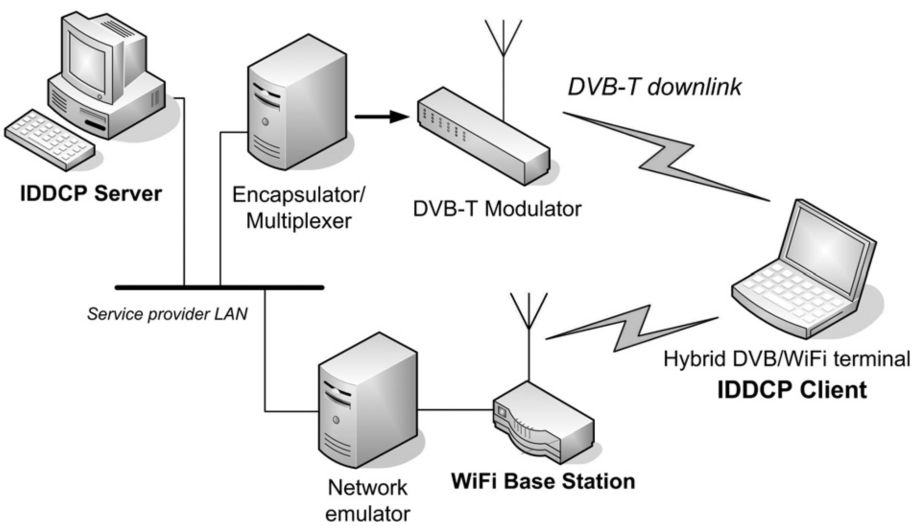

Fig. 3. Laboratory testbed for the validation and evaluation of the IDDCP protocol.

terminal is Linux-based and equipped both with a DVB-T receiver and a WiFi interface.

The IDDPC Client and Server modules were implemented as lightweight, stand-alone, platform-independent Java applications. The Java implementation allows for portability of the Client module to various kinds of terminals, including portable and handheld. In the specific Linux terminal, communication with the DVB interface is achieved via the open LinuxTV driver subsystem. The IDDCP Server module resides on a dedicated Linux-based workstation at the service provider side and is designed under a multi-threaded architecture to accompany multiple simultaneous client requests.

A first test is performed with a single Client to validate the proper operation of the protocol. The duration of the whole procedure (bind time) has an average of 5 s, and at the end the DVB interface has been assigned new parameters for IPv4 address and subnet, gateway address and IPv6 Global scope address. This result is illustrated by viewing the output of ifconfig in the DVB interface of the client before and after the IDDCP procedure (Fig. 4).

After the proper operation of the mechanism has been validated, its behaviour can be evaluated in relation to the condition of the access network. Specifically, the impact of round-trip delay and packet loss is examined. The quantity that is measured is the protocol bind time, defined as the time interval from the AUTOCONF to the BOUND state of the client (see Fig. 2).

The round-trip time is measured via ICMP Echo requests over the asymmetric connection (via the WiFi uplink to the Server and back via the DVB-T chain). In the laboratory set-up, RTT is restricted to 70 ms, but in a large-scale deployment it could increase due to the congestion or the complexity of the network – mainly of the return channel. The RTT can be increased via the NISTNet module, which inserts extra delay in the packets which traverse the return channel.

The bind time is measured at the Client, by an internal timer incorporated in the IDDCP Client module. Apart from the propagation delay of the messages, caused by the network itself, the Client spends some time waiting for the next ADVERTISE message (ADVERTISE messages are broadcast every 1 s), for the Server's REPLY, for the network interface to accept the new parameters and for the duplicate REPLY timeout to expire. The latter, as explained, is essential so as to ensure that the CONFIRM message has not been lost (such a loss could trigger a retransmitted REPLY). All timeout timers, which are needed to recover from lost messages both in the Client and the Server, have been set to 3 s. The first series of measurements show the effect of network RTT – as adjusted by the

```
Initial state
=============================

root@PERSEFONI:~/GARDIKIS/# ifconfig dvb0_1
dvb0_1    Link encap:Ethernet  HWaddr 00:0d:fe:02:ce:54
          inet addr:10.1.3.20  Bcast:10.255.255.255  Mask:255.255.255.0
          inet6 addr: fe80::10:20d:feff:fe02:ce54/64 Scope:Link
          UP BROADCAST RUNNING NOARP MULTICAST  MTU:4096  Metric:1
          RX packets:14840 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:994257 (970.9 KiB)  TX bytes:0 (0.0 b)

After IDDCP Configuration
=============================

root@PERSEFONI:~/GARDIKIS/# ifconfig dvb0_1
dvb0_1    Link encap:Ethernet  HWaddr 00:0d:fe:02:ce:54
          inet addr:172.16.1.29  Bcast:172.16.255.255  Mask:255.255.255.0
          inet6 addr: fe80::10:20d:feff:fe02:ce54/64 Scope:Link
          inet6 addr: 2000::10:20d:feff:fe02:ce54/64 Scope:Global
          UP BROADCAST RUNNING NOARP MULTICAST  MTU:4096  Metric:1
          RX packets:15515 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:1039491 (1015.1 KiB)  TX bytes:0 (0.0 b)
```

Fig. 4. Impact of the IDDCP mechanism: ifconfig output before and after dynamic configuration.

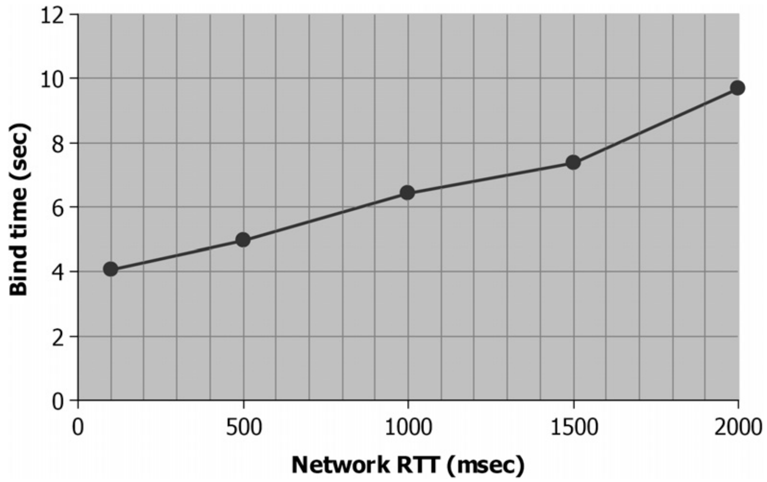

Fig. 5. Impact of the network round-trip time on the bind time of the IDDCP mechanism.

network emulator and measured via ICMP – to the bind time of the IDDCP mechanism. The results are derived in a loss-free environment and are shown in Fig. 5. Each result was calculated as an average of 10 iterations. A minimum bind time of 4 s is measured, although the network parameters have actually been configured much earlier, before the duplicate REPLY timeout expires.

The next step is the evaluation of the protocol in a lossy environment. Since all messages are conveyed over UDP, messages can be lost due to congestion or erroneous links. As explained, the mechanism has been designed to recover from losses via positive acknowledgements and retransmission procedures.

Packet loss conditions are caused by the network emulator, in which return-channel packets are uniformly dropped with a given probability. Due to timeout expirations and retransmissions, the total bind time is prolonged. Measurements were derived for various packet loss rates and for a fixed RTT of 500 ms. Each result was calculated as an average of 30 iterations. Two sets of measurements are presented in Fig. 6, for timeouts of 2 and 5 s, respectively, both in the Client and the Server.

It is normal that a higher timeout value results in prolonged bind time for a given packet loss rate. In a large-scale network, the timeouts of the protocol should be set as low as possible, but sufficiently above the RTT of the network, so that delayed

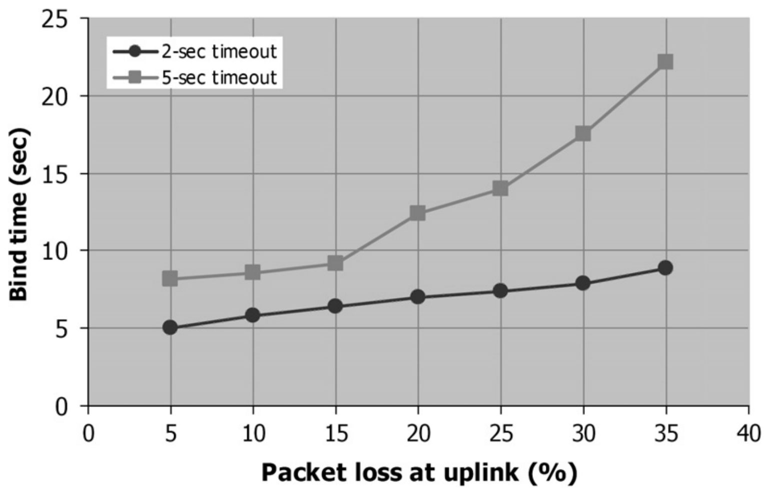

Fig. 6. Impact of the network packet loss on the bind time of the IDDCP mechanism.

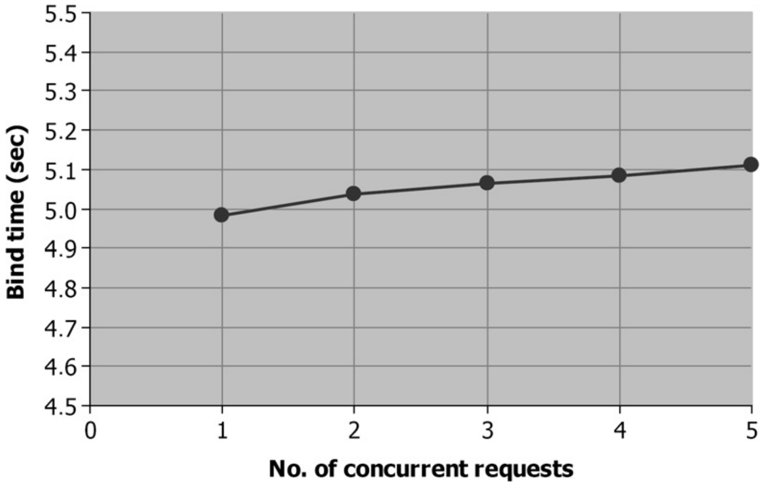

Fig. 7. Performance of the mechanism under a multi-user load.

packets are not misinterpreted as lost. A dynamic adjustment of the timeout according to the measured network delay would be a more flexible and efficient approach.

All the aforementioned tests were carried out under a single-client scenario. In order to evaluate the operation of the Server under multiple concurrent requests, a multi-user scenario was employed. Up to five Client modules were used, running the request-bind process continuously, so that at any time the Server was processing concurrent requests. The average bind time for all Clients was again recorded, as depicted in Fig. 7. Loss-free channels were assumed, with a typical RTT of 500 ms.

This test validated the proper operation of the multi-threaded Server module serving multiple Clients concurrently and showed that, for a restricted number of simultaneous requests, the overhead introduced in the bind time is negligible.

In conclusion, the evaluation procedure of the proposed mechanism showed that the algorithm is operable and stable, has a smooth behaviour under large-delay conditions, and can recover from packet loss. Multi-client operation was also validated.

6. Conclusions

This article discussed the issue of dynamic configuration of IP parameters of terminals in broadcasting networks. Via an overview of the broadcast network scenario, the need of such a mechanism was justified, particularly in terrestrial networks, where handovers and switches among broadcasters are common. Through an overview of the particularities of a broadcasting network and the requirements for dynamic configuration, it was explained why existing protocols such as DHCP cannot be used "as-is". A new client–server mechanism was proposed, namely IDDCP (IP-over-DTV Dynamic Configuration Protocol) and was extensively described via its message types, operational description and state diagram. This protocol is designed to provide simultaneous IPv4/IPv6 configuration and is well tailored to suit the requirements of an IP/DTV interactive network via a simplified yet fully functional and scalable approach, which can be easily implemented at the IP-level in all existing satellite and terrestrial/handheld terminals. The proposed protocol was implemented in platform-independent lightweight Java modules, and its behaviour was evaluated in relation to network RTT, packet loss, and multi-Client operation. The research effort referred to in this paper was carried out in the frame of the "IP-over-DVB" workgroup of the IETF [11].

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