Distributed NQoS provision in Interactive DVB-T systems

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***Abstract*—This paper discusses a Distributed Network Quality of Service (NQoS) provision approach in decentralized interactive DVB-T systems (IDVB-T), enabling for scalable and fault tolerant operation. The paper describes the design and overall architecture of a regenerative IDVB-T infrastructure, where network resource allocation and service classification processes are performed at local level within each intermediate distribution node (Cell Main Node CMN), setting the basis for a CMN-to-CMN NQoS provision. Validity of the proposed approach is experimentally verified, and the test-results are compared against the aggregated and federated NQoS provision approaches, indicating similar performance but better scalability and fault-tolerant design.**

***Index Terms*—Distributed NQoS, Interactive DVB-T, Network Resource Allocation.**

I. Introduction

The advent of Digital Video Broadcasting (DVB) standard and its application over terrestrial channels (DVB-T) enabled the exploitation of digital TV networks not only for the provision of MPEG-2 TV programmes, but also as part of IP networking infrastructures (DVB/IP) capable to interconnect Service Providers (i.e. IPTV, E-mail, VoIP providers) and End Users to each other. Such exploitations of digital TV networks constitute the so-called Interactive DVB-T (IDVB-T) environments, where EUs can interact with SPs for accessing, manipulating, customising and personalising the provided services.

Research efforts carried out during the last decade in the field of Interactive DVB-T resulted in two design approaches for such interactive system implementations, exploiting either centralized architectures [1], [2], [3] or decentralized ones [4], [5], [6], each one accommodating different business plans and market exploitation strategies for the broadcaster. More specifically, in centralised IDVB-T architectures where the broadcaster maintains the administration, control and management of the entire IDVB-T infrastructure, the IP Service Providers and the corresponding End Users are forwarding their IP data directly to the broadcasting platform (DVB-T) via uplinks (e.g. PSTN, ISDN, WLAN, UMTS, etc.), while receiving IP traffic destined to them directly via the VHF/UHF spectrum (downlink). On the other hand in decentralised IDVB-T architectures, the broadcaster maintains only part of the system administration, while leasing/selling/sharing networks resources that are co-managed and exploited in collaboration with others that act as ”brokers”. For this reason, in decentralised architectures the communication between SPs/EUs and the broadcasting platform is indirect, and their interaction is carried over intermediate distribution nodes (namely Cell Main Nodes-CMNs), which are responsible for a) gathering all IP traffic stemming from their respective SPs/EUs and forward it via uplinks to the DVB-T platform, and b) receiving IP traffic that is broadcasted by the DVB-T platform in VHF/UHF channels processing, filtering and finally routing it to the corresponding SPs/EUs, whichever is appropriate.

Although decentralised IDVB-T implementations predominate over centralised ones when scalability and single-point-of-failure issues come to the foreground, it is obvious that fixed and static allocation of the available resources among the distribution nodes (brokers) will not offer optimum spectral efficiency, especially when time varying traffic is generated from each CMN. Therefore, a real time and dynamic management of the available bandwidth is required, in order to enhance the capability of DVB-T platforms as a networking infrastructure and allow the provision of multiple kinds of services. Towards this, the consequent exploitation of Network QoS (NQoS) provision schemes is mandatory, allowing an optimised provision of heterogeneous type traffics in respect to the available spectrum.

Existing NQoS provision schemes (e.g. DiffServ, IntServ, MPLS) utilize (among others) service-classification and queue-management techniques, where the former is used for differentiating each service flow according to specific priority level(s), while the latter is exploited for providing the requested network resources to each differentiated service flow in a way that meets its network requirements (i.e. bandwidth, latency, jitter, loss). In this context, NQoS implementation in IDVB-T systems followed either an aggregated approach where both service classifier and the queues manager reside within the DVB-T platform [7], [8], [9], [10], or a federated one where the service classifier resides within each CMN and the queue manager within the DVB-T broadcasting platform [11].

Nevertheless, in both of the above NQoS implementation approaches the most demanding task of queue-management (as a matter of processing power and memory allocation) takes part within a single unit of the DVB-T platform; an issue that may lead to degraded system's efficiency, scalability limitations besides making the overall infrastructure prone to Single-Point-of-Failure issues. Towards alleviating this issue the paper proposes a distributed NQoS provision approach, where both Service Classifier and the Queue Manager are located within each CMN, thus "distributing" NQoS provision processes among all CMNs for improved system's efficiency and scalability.

Following this introductory section, the rest of the paper is structured as follows: Section 2 presents the proposed distributed NQoS provision approach, while Section 3 elaborates on its initial validation and comparison with the aggregated and federated approaches. Finally, Section 4 concludes the paper and identifies fields for further research.

II. DISTRIBUTED NQOS PROVISION APPROACH

Fig.1 depicts the overall configuration of a decentralised IDVB-T platform, where NQoS provision is applied in a distributed approach, featuring service classification and network resource allocation within each CMN (Intra-NQoS unit). In this configuration, each service flow stemming from SPs/EUs in the access networks enters the IDVB-T domain via the corresponding CMN, where it is differentiated and classified according to its network resource requirements and QoS priority level, prior to be allocated any resources that match the specific NQoS requirements. Towards these, service differentiation, classification and network resource allocation processes are performed by the Intra-NQos unit (see Fig.2) that utilises: i) a Monitor module; ii) a Call Admission Control (CAC) mechanism; iii) a Service Classifier (SC) module and iv) a Network Resource Allocation (NRA) element.

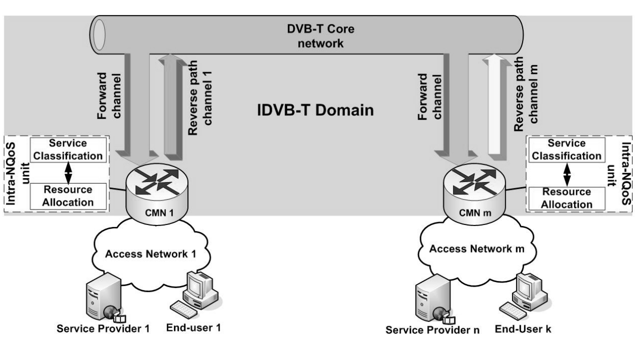

Fig. 1. Configuration of IDVB-T exploiting a distributed NQoS provision approach

More specifically, the Monitor module is used for identifying the NQoS requirements of the services stemming from the Service Providers and for evaluating the performance of the applied resource allocation techniques. The former is achieved either by parsing an existed Service Level of Agreement (SLA) or by analysing the services flows (e.g. content type, packet header attributes) while the latter can be performed by assessing NQoS metrics such as bit rate, jitter, latency and packet losses.

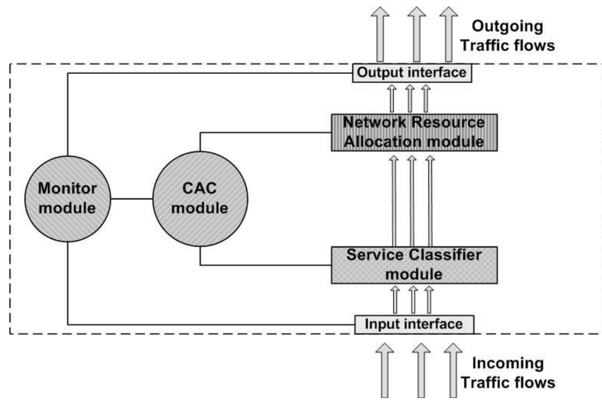

Fig. 2. CMN Intra-NQoS unit

The Call Admission Control mechanism is used for checking the requested network resources (as presented by the Monitor) availability in the IDVB-T network. Towards this, CAC has to be informed for the free resources in its uplink and the DVB-T downlink (Forward Channel). This information can be acquired from the local Monitor module by metering the aggregated outgoing and incoming IP rate of the uplink and DVB-T link respectively. Table I presents a simple algorithm utilised by CAC for checking the network resources availability. If the algorithm grants the resource reservation, CAC will instruct the Service Classifier and Network Resource Allocation modules to take the appropriate actions, while if

TABLE I
ALGORITHM FOR CHECKING NETWORK RESOURCES AVAILABILITY

S_{RP}: Current aggregate IP rate of the reverse path
C_{RP}: Overall IP Capacity of the reverse path
S_{DVB}: Current Aggregate IP rate of the DVB-T link
C_{DVB}: Overall IP Capacity of the DVB-T link
N_{ip}: New Service requested bit rate

If (C_{RP} >= N_{ip} + S_{RP}){
  If(C_{DVB} >= N_{ip} + S_{DVB}){
    S_{RP}= S_{RP}+ N_{ip}
    S_{DVB}= S_{DVB}+ N_{ip}
    Resource allocation granted}
  else
    {Resource allocation not granted
    exit}}
else
  {Resource allocation not granted
  exit}

not it could deny transferring the service or instructing for its transportation under the Best Effort scheme. Another option would be the reallocation of the already reserved network resources according to some criteria (i.e. service priority level). The reallocation could take place in a local level (source CMN), if it is a matter of resource availability in the reverse path channel or even among CMNS, if it is a matter of resource availability in the DVB-T link, with the latter requiring the real time coordination of the CMNs Intra-NQoS units via inter-management communication signalling and processes. It should be noted, however, that the inter-CMN management is out of this papers scope, thus constituting a field for further research.

The SC module (see Fig.3) utilizes a filtering mechanism to segregate the incoming services flows by analysing their packets header fields (i.e. address, protocol, port number), and forwards each one to the respective marker. The markers, in turn, assign a specific value, into an appropriate field of each packet header, i.e. Differentiated Service (IPv4), Traffic Class (IPv6) or VLAN (Ethernet).

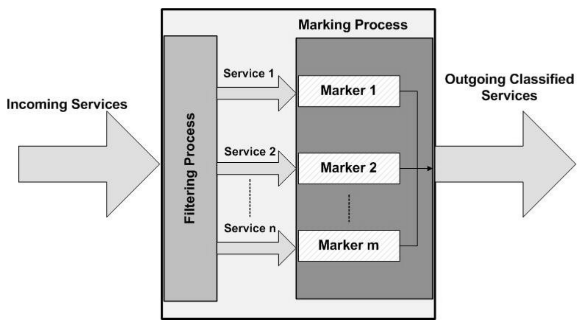

Fig. 3. Service Classifier module

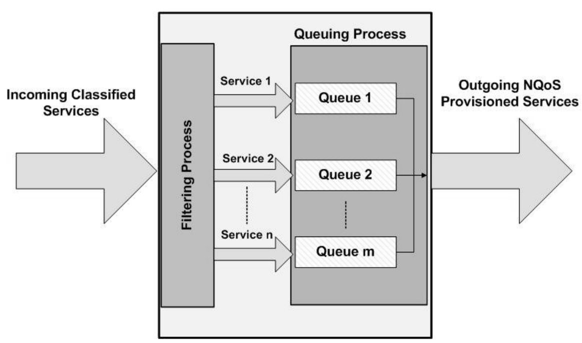

Fig. 4. Network Resource Allocation module

Following, the marked services are forwarded to the Network Resource Allocation element (see Fig.4, where a filtering mechanism segregates the incoming marked services based on the value assigned by the SC module and forwards them accordingly to a specific queue. Each queue reserves a portion of the available network resources according to the NQoS requirements of the incoming services. The outgoing NQoS provisioned traffic is then forwarded to the IP/DVB multiplexer, via the reverse path, and broadcasted using a DVB-T transmitter. Towards avoiding scalability issues, it is possible to assign on the same marker (SC module) or queue (NRA module) two or more services sharing the same NQoS requirements.

III. Experimental validation of the proposed Distributed NQoS provision approach

A. Testbed

Towards validating and comparing the performance of the proposed distributed NQoS provision approach against the aggregated and federated ones, several experiments were conducted under real transmission/reception conditions environment. More specifically an experimental IDVB-T test-bed was created including:

- The DVB-T platform, located at the premises of Technological Educational Institute of Crete (TEIC), where the common DVB-T stream is created in channel 40 of the UHF band (i.e. 622-630 MHz), utilizing 8K operation mode with 16QAM modulation scheme, 7/8 code rate, 1/32 guard interval and the multi-protocol encapsulation mechanism (MPE) for the distribution of IP datagrams.
- A NQoS aware router located in the DVB-T platform, able to analyse and forward the networking traffic stemming from the CMNS according to its network requirements. This router is exploited from the aggregated and federated NQoS provision approaches.
- A NQoS aware CMN (namely CMN 1 in Fig.1), located at TEIC premises , enabling SPs to provide IPTV services. The communication between this CMN and the DVB-T platform was based on a one-way point-to-point link of IEEE 802.11 g technology (reverse path channel 1 in Fig.1) while the interconnection between SPs and CMN1 was carried out via a IEEE 802.11g WiFi network (Access Network 1 in Fig.1).
- A NQoS aware CMN (namely CMN m in Fig.1), located in a rural area 10km away from the DVB-T platform, where only PSTN (reverse path channel m in Fig.1) is currently available, enabling users to access the offered IPTV services. The interconnection between EUs and CMN m was carried out via a local IEEE 802.11g wireless network (Access Network m in Fig.1).

In order to emulate, however, a real service-scenario, where IPTV services are stemming from multiple different Service Providers located at CMN 1 and are accessed from End Users located at CMN m, ”gst-launch” utility of the Gstreamer framework [12] was used for the IPTV services provision, configured so that multiple IPTV streams over IP/UDP to be delivered from a single PC (Service Provider 1 in Fig.1) via the same network interface, but over different communication/protocol ports. Another PC (End User k in Fig.1) was receiving though multiple instances of ”gst-launch”, the IPTV services. Each IPTV service was consisting in streaming the same MPEG-2 video file encoded at a Constant Bit Rate (CBR) of 1.5 Mbps.

The total available bandwidth of the DVB-T stream (20.5 Mbps) was statically allocated between the TV and IP services as follows: 12.5 Mbps were dedicated to a bouquet of 4 digital TV programmes (MPEG-2 live and non-live broadcasts), while the remaining 8 Mbps were dedicated to IP services. In this context, the overall network performance of the described IDVB-T infrastructure was initially evaluated, providing one IPTV service for a 5 minutes evaluation period. The experimental results indicated an average one way delay of 39.56 ms [13] and no packet losses [14].

B. IDVB-T's network performance evaluation with NQoS disabled

The next experiment was designed in order to evaluate the network performance when multiple IPTV streams compete for the network resources under the Best Effort scheme, i.e. when the services require more than 8Mbps (in total) for efficient provision. Towards this, 6 IPTV services were provided simultaneously for a period of 300 sec. The experimental results, regarding the average one-way delay and the packet loss ratio of each IPTV service, are depicted in Figs.5 and 6 respectively. The lack of NQoS provision and the competition

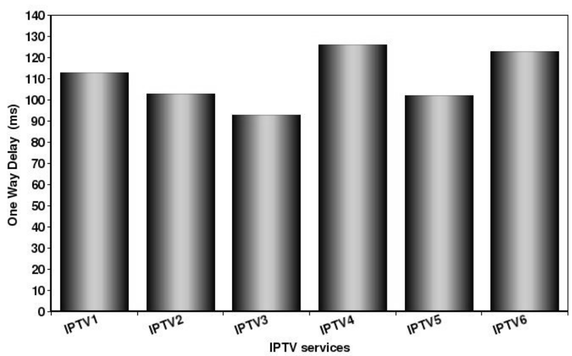

Fig. 5. One Way Delay without NQoS provision

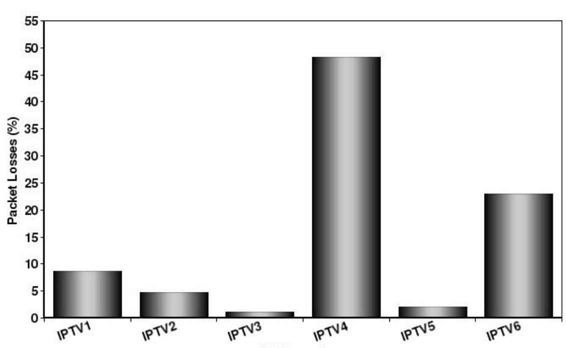

Fig. 6. Packet Losses without NQoS provision

for network resources among the flows increased their latency, which combined with the losses resulted in a degraded network performance level. It is noted here that the observed variation of losses among the services is not an indication of service differentiation from the network. In contrast it has to do with the arrival time of each service in the congested DVB-T link (i.e. if the link's queue could store the packets or not). This was verified by repeating the experiment while changing the transmission sequence of the services (i.e. first IPTV6, second IPTV4, etc). The experimental results verified the variation of losses in accordance with the transmission sequence.

C. IDVB-T's network performance evaluation with NQoS enabled

The next sets of experiments were created for comparing the NQoS performance of the proposed distributed approach with the aggregated and federated ones. For all the different approaches the same as previous 6 IPTV services were provided for an evaluation period of 5 minutes. In addition it was assumed that the services NQoS requirements extracted by the Monitor module were as follows; for the IPTV1 and IPTV2 (High Priority Services) the one-way delay to be under 100ms and with no packet losses, for IPTV3 and IPTV4 (Medium Priority Services) the one-way delay to be under 400ms and with packet losses under a maximum threshold of 7% while the last two (IPTV5, IPTV6) could share the remaining available network resources (Low Priority Services).

In this context, IP traffic stemming from the IPTV provider passes to Service classifier (see Fig.3), where it is classified accordingly to its priority level. More specifically, a filtering mechanism segregates the incoming IPTV streams by analysing their UDP header field (i.e. port number), and forwards each one to the respective marker. This marker, in turn, assigns a specific value, into the Differentiated Service (DS) field of each IP packet. As a result, the output of the module is the marked IPTV streams, which then in turn are forwarded to the Network Resource Allocation module (see Fig.4). This module utilizes a filtering mechanism, which segregates the incoming marked IPTV streams by analysing the DS field of the IP packet headers and forwards them accordingly to a specific queue. Each queue reserves a portion of the available network resources according to the priority level of every IPTV service as defined in their associated NQoS requirements. The outgoing NQoS provisioned traffic is then forwarded to the IP/DVB multiplexer and broadcasted using a DVB-T transmitter. It is noted here that the service classifier was implemented by exploiting the marking capabilities of iptables application [15] while the resource allocation module was realized by utilizing the tc toolkit of the iproute2 application [16] and the HTB queuing discipline [17]. Table II indicates the nodes hosting the Service Classifier and Resource Allocation modules in accordance with the enabled NQoS approach. The experimental results, regarding the one-way delay are depicted on Fig.7 while for the losses at Table III. It is clear from the results that the proposed distributed NQoS approach performs equally well with the other two ones, while being by its design more scalable and fault tolerant (avoiding Single-point-of-Failure).

TABLE II
ACTIVATION OF MODULES ON THE THREE NQOS PROVISION APPROACHES

	Service Classifier	Network Resource Allocation
Aggregated	Router at DVB-T	Router at DVB-T
Federated	CMN1, CMN m	Router in the DVB-T
Distributed	CMN 1, CMN m	CMN 1, CMN m

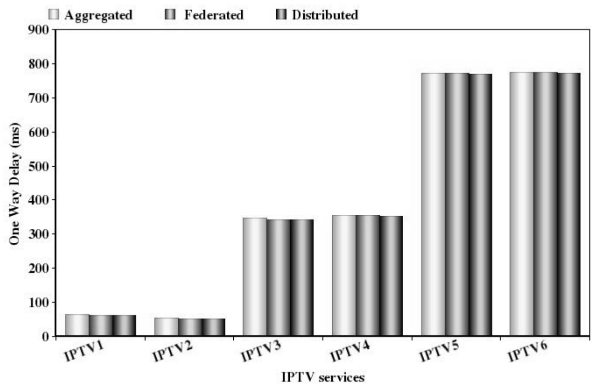

Fig. 7. One Way Delay for the different NQoS provision approaches

TABLE III
IPTV PACKET LOSSES FOR THE DIFFERENT NQOS PROVISION APPROACHES

	Aggregated	Federated	Distributed
IPTV1	0%	0%	0%
IPTV2	0%	0%	0%
IPTV3	5.65%	5.78%	5.67%
IPTV4	6.42%	6.47%	6.06%
IPTV5	53.89%	53.88%	53.88%
IPTV6	53.89%	53.89%	53.88%

IV. CONCLUSIONS

This paper presented a distributed QoS provision approach in decentralized IDVB-T systems, where each intermediate node (CMN) was enhanced with resource allocation and service classification capabilities (CMN Intra-NQoS units), towards enabling for the delivery of IP services according to their network requirements. An initial validation was performed by conducting a number of tests under real transmission/reception conditions, concerning the NQoS effectiveness of the proposed approach against the aggregated and federated ones. It was experimentally verified that the proposed distributed NQoS approach performed equally well with the other two ones, while being by its design more scalable and fault tolerant.

As a future work, the authors will focus on the design, implementation and validation of the inter-CMN management communication, which will allow for an intelligent inter-coordination of the CMNs Intra-NQoS units, towards exploiting in an optimised way the available network resources. In addition an effort will be carried out towards examining the effectiveness of the distributed NQoS provision approach when more than one CMN is involved in the network resource reallocation process.

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