Exploiting Digital Switchover for Broadband Services Access in Rural Areas

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***Abstract*—The paper discuses how the imminent transition to the digital terrestrial television in UHF (Digital Switchover) could be employed towards enabling always-on connectivity and triple-play services access even from rural and dispersed locations, i.e. in areas where no termination/connection exists between the local PSTN exchanger and the optical fibre core backbone. Exploiting the European digital video broadcasting standard in regenerative configurations, the paper introduces an architecture that utilises the television stream as a common broadband infrastructure, capable to deliver not only custom digital television bouquets, but also and most predominant, to provide access to triple-play services. Utilising this television beam in backhaul (middle-mile) configurations it extends the core backbone to reach rural and dispersed locations, enabling therefore the immediate and cost-effective deployment (in these areas) of technologies that provide for always-on connectivity, such as WLAN, xDSL, etc.**

***Index Terms*—Broadband access, Digital switchover, IP/DVB testbed, Pilot operation, Triple-play services**

I. INTRODUCTION

Delivery of triple-play and always-on services depends not only on the access network, the so-called "last mile", but also on a means of connection from the local "point of presence" (typically a local exchange building) to the mainline or high-capacity backbone networks, which form part of national and international data transmission networks. This connection, which is known as backhaul and has been called the "middle mile", is a significant issue for accessing broadband services in small cities and/or in rural areas that are away from the national backbone, due to technology limitations and cost reasons, since high-capacity networks are normally found in large towns, and obtaining connection to them constitutes a challenge with technological/networking and cost parameters [1].

Taking into account the imminent transition from analogue to digital broadcasting in UHF (Digital Switchover – DSO) [2]– in most European countries it is already underway, while in others, such as in Africa, Latin America and Asia it is scheduled for the next years [3], [4]– this paper anticipates that if DSO is properly adopted and the resulting spectrum dividend is suitably exploited, it may constitute the vehicle not only for the delivery of digital TV bouquets but also for paving the way towards a networking infrastructure providing always-on connectivity and triple-play services access even in rural areas. In this respect, it proposes an architecture that utilises the terrestrial digital video broadcasting technology (DVB-T) in regenerative configurations, and exploits the resulting spectrum dividend in terms of bit-rate allocation rather than in terms of frequency allocation, for the creation of a common networking infrastructure delivering custom MPEG-2 television programmes and IP services, to any citizen located within the entire broadcasting area. Exploitation of this common infrastructure (i.e. the DVB-T stream) in backhaul configurations enables the low-cost (marginal cost) diffusion of advanced communication technologies that provide for always-on connectivity, such as xDSL, in rural and dispersed locations, where custom PSTN/ISDN is only available. Early work found in [5], [6] on the concept of exploiting DSO for broadband services access, especially in rural areas, guided the current work.

Following this introductory section, the rest of the paper is structured as follows: Section II describes the overall architecture of such a common networking infrastructure, capable to provide citizens of rural and dispersed locations with triple-play services access and always-on connectivity, while Sections III and IV analyse the design/configuration of each building module/block. Section V elaborates on the validity of the proposed DSO concept/architecture through a set of experimental tests, which have been conducted on a prototype, implemented according to the design specifications. Finally, Section VI concludes the paper giving also directions for future research.

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II. Overall System Architecture

The overall architecture of such an infrastructure is depicted in Figure 1. It consists of two core subsystems: a) a central broadcasting point (regenerative DVB-T), and b) a number of distributed Cell Main Nodes (CMNs) located within the broadcasting area. Each CMN enables a number of users/citizens (geographically neighbouring the specific CMN) to access IP unicast services that are hosted/provided by the entire infrastructure (e.g. by the ISP & Multimedia provider as depicted in Figure 1). The communication between the users and the corresponding CMN (access network) is achieved via broadband point-to-multipoint links (i.e. WLAN, xDSL). The CMN gathers all IP traffic stemming from its own users and forwards it to the central broadcasting point (UHF transmission point visible by all CMNs) via dedicated point-to-point uplinks. IP traffic stemming from all CMNs is received by the broadcasting point, where a process unit filters, regenerates and multiplexes them into

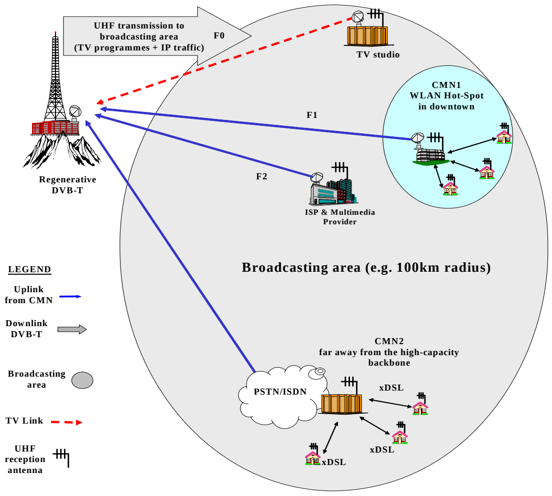

Figure 1. Overall architecture of common broadband infrastructure.

a single transport stream (IP-multiplex) along with the digital TV programme(s) stemming from the TV broadcaster(s) (TV studio), towards forming the final DVB-T "bouquet". Each user receives the appropriate IP reply signals indirectly via the corresponding CMN, while receiving custom digital TV programme (e.g. MPEG-2) and IP multicast data (e.g. IP-TV) directly via the common DVB-T stream (by utilising a simple/custom UHF antenna). In such configuration, both reverse and forward IP data traffic are encapsulated into the common DVB-T stream, thus improving the flexibility and performance of the networking infrastructure. Furthermore, the cellular conception that is adopted utilises the DVB-T stream in a backbone topology, which interconnects all cells that are located within the broadcasting area. Thus, a unique virtual common IP backbone is created, which is present at every cell via its CMN. The IP traffic of this IP backbone is supplied by the DVB-T bit stream. Users access the network via the appropriate CMN.

III. Configuration of the Regenerative DVB-T

The configuration of the regenerative DVB-T (depicted in Figure 2) is capable to: i) receive the users/providers IP traffic over the uplinks (via the appropriate CMN – see F1, and PSTN/ISDN uplink in Figure 1), ii) receive any local digital TV programme(s) along with IP multicast and Internet services, stemming from the TV studio broadcaster and the ISP & Multimedia Provider correspondingly (see TV Link and F2 in Figure 1), and iii) create and broadcast a common UHF downlink that carries the digital TV programme(s) and the IP data (targeting to all CMNs located within the broadcasting area).

Following the configuration depicted in Figure 2, the multiplexing device receives any type of data (IP and/or digital TV programmes), adapts them into a DVB-T transport stream (IP to MPEG-2 encapsulation), and finally broadcasts this DVB-T stream to the entire broadcasting area following the DVB-T standard (COFDM scheme in the UHF band). In this respect, all users and providers contribute to the creation of a backbone (DVB-T stream), which is present and available within the entire broadcasting area.

An actual exploitation of this architecture can be realised for establishing/creating backhaul (middle-mile) networks that allow the deployment of xDSL infrastructures in rural and dispersed locations, towards enabling not only access to triple-play services, but also and most predominant always-on connectivity. The deployment of xDSL access networks require the Head-End unit (i.e. DSLAM) to be placed close at a high-capacity core backbone (e.g. fibre), while the end-user equipment to be located no further away than a few kilometres from the “point-of-presence” (e.g. 5km from the DSLAM). As a result, in rural and dispersed areas that are away from the core backbone, xDSL deployment cannot be realised, unless extension of the high-capacity backbone is achieved in order to reach these areas; involving however installation and operational costs. Taking into account that DVB-T transmissions utilise coverage areas of many kilometres (e.g. 100km), the proposed configuration (see Figure 2) can be exploited for realising the common DVB-T stream in middle-mile/backhaul configurations, extending the core backbone within the entire broadcasting area and making it available/present at any CMN within the coverage footprint. Such a backhaul solution that conforms to the proposed architecture is presented in the following section (Section IV), describing an ADSL-based CMN that is placed away from the national backbone and the service provider (ISP & Multimedia Provider in Figure 1), enabling citizens for always-on connectivity and access to triple-play services.

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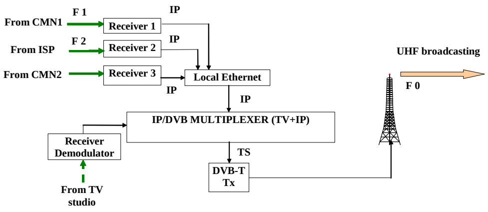

Figure 2. Regenerative DVB-T Configuration.

IV. THE MIDDLE-MILE CELL MAIN NODE CONFIGURATION

In rural and dispersed areas that are far away from a core backbone network (e.g. fibre) and where the local PSTN exchanger is currently available, access to triple-play services and always-on connectivity cannot be performed, unless extension of the core backbone to these regions is accomplished.

For such regions/cases, the exploitation of the proposed architecture arises as a very promising solution (and to some extent natural), enabling not only for triple-play services provision but also for always-on connectivity via cost-effective (marginal cost) extension of the core backbone. Primarily, the common DVB-T stream enables broadcast and multicast data (such as digital TV MPEG-2 and IP-TV services) to be present and available within the entire coverage area. Users/citizens, located even in rural and dispersed regions, can easily and cost-effectively access them by utilising a simple/custom UHF reception antenna and the corresponding DVB-T reception equipment at their own premises. Secondly, the exploitation of the common DVB-T stream in backhaul/middle-mile configurations, allows the fast/immediate interconnection between the core backbone and any CMN within the entire broadcasting footprint. In such an approach, the core backbone is in a way transferred even to rural-based CMNs, enabling the deployment of ICTs that provide for always on connectivity (e.g. ADSL).

The overall configuration of such a rural-based CMN is depicted in Figure 3. It comprises DVB-T compliant equipment for receiving the common DVB-T stream (UHF channel), a reverse path channel (uplink communication from this CMN to the regenerative DVB-T) making use of the PSTN/ISDN technology (already available in this area) and an ADSL-based access network. At this point it should be noted that the deployment of the ADSL technology in the access network would not have been feasible due to high costs for the backhaul connection (physical connection between this rural-based CMN and the nearest optical backbone network). However, the proposed configuration enables the low-cost and fast deployment of such an ADSL network, by exploiting the common DVB-T stream as a backhaul and middle-mile infrastructure, capable to interconnect the core backbone (present at urban areas) with the rural-based CMN. Such an approach, allows rural citizens to maintain always-on connectivity (over the ADSL network) and triple-play services access over the common UHF beam.

Upon a user's request for personalised/unicast IP services that are hosted by the core high-capacity network (e.g. Internet), the corresponding IP data-requests are forwarded by the ADSL modem to the IP-DSLAM module, which takes the responsibility to forward them to local Ethernet of this CMN (rural-based CMN). The local Ethernet, in turn, forwards them to the uplink interface module, which passes them to the central broadcasting point (regenerative DVB-T) via the uplink chain (PSTN/ISDN network). For maintaining one-way communication between the CMN and the regenerative DVB-T, the CMN comprises a routing mechanism, which "blocks" any downlink data traffic from the regenerative DVB-T to the CMN via the PSTN/ISDN. Finally, the data requests reach the "ISP & Multimedia Provider" via the common DVB-T UHF channel. The corresponding reply signals, are provided by the "ISP & Multimedia Provider" to the regenerative DVB-T over the uplink (F2 in Figure 1), and reach the Ethernet of the rural-based CMN via the DVB-T UHF channel. Users receive the corresponding reply data via their CMN Ethernet over the IP-DSLAM module. It should be noticed that in such configuration (regenerative) both reverse and forward IP data traffic are encapsulated into the common DVB-T stream (i.e. all IP data are in the same stream along with the digital TV programmes / bouquet). Multicast IP services (e.g. IP-TV, IP-Radio stemming from the "ISP & Multimedia Provider"), are received by all citizens (rural and urban ones) directly via the common DVB-T stream, through a custom UHF antenna.

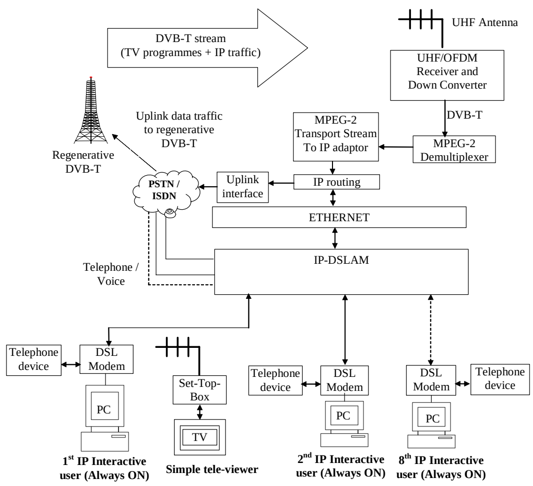

Figure 3. CMN Configuration (ADSL case).

V. PERFORMANCE EVALUATION OF A PROTOTYPE TEST-BED

For a more concrete example of the general setting just discussed, Figure 4 illustrates a prototype testbed platform that operates 24-hours-a-day in the city of Heraklion in Greece. With reference to this figure, the platform includes:

1. The regenerative DVB-T, where the common DVB-T stream is created in UHF channel 40 (622-630MHz), utilising 8K operation mode

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with 16QAM modulation scheme, 7/8 Code Rate, 1/32 Guard Interval in, and the multi protocol encapsulation mechanism (MPE) for the distribution of IP datagrams;

2. One urban-based CMN (namely CMN1 in Figure 4), located near the core/optical broadband backbone (Heraklion downtown). The communication between CMN1 and the regenerative DVB-T is based on one-way point-to-point link that makes use of the IEEE 802.11b technology. Since this technology provides in principle for full-duplex communication, a routing mechanism was integrated at the regenerative DVB-T side, in order to maintain one way-transmission (from CMN1 to the regenerative DVB-T). This CMN accommodates an active user/citizen, who creates, manipulates, hosts and provides access to his own multimedia services, realising in this way an implicit service/content provider (e.g. a Multimedia provider);
3. An active user/citizen located within the Heraklion downtown (about 500m from the regenerative DVB-T), providing Internet access (ISP) and IP-TV/Radio services (IP Multicaster) to the entire infrastructure. The communication between this active user and the regenerative DVB-T is over a free space optical (FSO) link, see Figure 4;
4. A local TV broadcaster, who exploits the proposed common infrastructure for transmitting its own analogue TV programme in digital mode (simulcast). This broadcaster (TV studio) maintains all the required equipment for the digital conversion of its own TV programme and a microwave uplink for providing it to the regenerative DVB-T (see Figure 4). Furthermore, and in addition to the live TV programme, the TV studio also distributes one digital TV thematic programme of non-live content (e.g. local cultural events and/or religious content the IPR's of which are hold by the TV studio/broadcaster);
5. A rural-based CMN (CMN2 in Figure 4), located 30 kilometres from the regenerative DVB-T and in an area where only PSTN/ISDN is currently available, which cannot (primarily and in-principle) enable for always-on connectivity. Exploiting, however, the common DVB-T stream in backhaul and middle-mile configurations, this CMN (placed within the same building as the local PSTN exchanger) utilises PSTN technology in the uplink, and ADSL technology in the access network for enabling always-on connectivity and access to triple-play services.

The total available bandwidth of the DVB-T stream (20.5Mbps) was allocated among two digital TV programmes (MPEG-2 live and non-live broadcasts, 10Mbps) and five IP-TV multicast streams (MPEG-4 stream stemming from the IP Multicaster, 6.5Mbps), all of them being accessed directly via the common DVB-T stream (i.e. via a custom UHF antenna). The remaining bandwidth in the DVB-T stream (i.e. 4Mbps) was allocated for Internet connection provided by the ISP, and for unicast multimedia services access provided by the Multimedia provider (see Figure 4). Users/citizens access these Internet and multimedia services indirectly via the appropriate CMN.

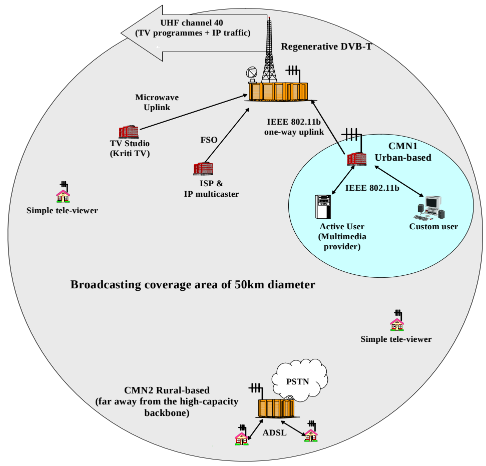

Figure 4. The prototype IP/DVB networking infrastructure.

The remainder of this section evaluates the performance of the prototype and validates the proposed concept in enabling triple-play services access and always-on connectivity (especially to citizens in rural and dispersed areas) via a representative set of experiments in respect to quality of the IP broadcast/multicast services and in relation to the network throughput that the ADSL rural citizens utilise during unicast/Internet services access.

Specifically, the quality of the one-way broadcast/multicast IP services was evaluated in terms of packet inter-arrival jitter, utilising a users/citizen accessing one IP-TV programme (MPEG-4, 1Mbps provided by the IP multicaster) via his UHF antenna. **Error! Reference source not found.** gives the graphical representation of the inter-arrival jitter during a 60 seconds evaluation period. This period is enough for the prototype to reach a stable state. The experimental results indicated a maximum inter-arrival jitter of 10,38ms, a minimum of 0,85ms and an average of 7,03ms, resulting in good QoS [7].

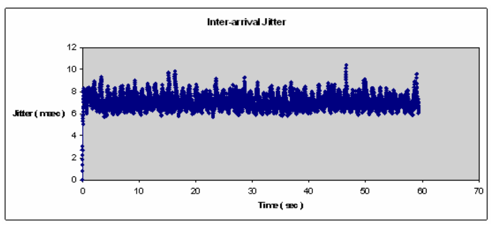

Figure 5. Inter-arrival jitter during the provision of an IP-TV multicast to an ADSL user in CMN2.

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In respect to the capability of the proposed infrastructure in providing always-on connectivity to rural citizens, network throughput experiments were conducted, utilising an ADSL user located in CMN2 accessing Internet/multimedia interactive services hosted by the Multimedia provider. It should be noted that during these experiments the communication between CMN2 and the regenerative DVB-T (uplink) was over a single PSTN channel, towards setting-off the simplicity and cost-effectiveness of the proposed approach in enabling the low-cost and fast deployment of ADSL networks in rural and dispersed areas. It was experimentally verified that CMN2 can provide its ADSL users with a total of about 3Mbps (evenly shared among them in the case of simultaneous access) for Internet/multimedia services access (a matter of the DVB-T overhead/encapsulation section and given that TCP/IP parameters are properly tuned, e.g. TCP/IP Window Size). A graphical representation of the network throughput when a single ADSL user accesses Internet and/or on-demand multimedia services is depicted in Figure 6.a. In the case where other technologies are used for the uplink (e.g. ISDN) [8], such a rural-based, CMN could provide IP interactive services at higher rates, depending on available uplink bandwidth and appropriate DVB-T bandwidth allocation between the digital TV programmes, the IP multicasts and the interactive IP services. For example, Figure 6.b indicates the throughput of the same ADSL user, when PSTN technology is utilised in the uplink (rural-CMN to Regenerative DVB-T communication) and 8Mbps were allocated for IP unicast services in the common DVB-T stream (i.e. the bandwidth initially allocated to one live MPEG-2 TV programme was re-allocated to IP unicast services), resulting in an optimum throughput of about 6.25Mbps.

VI. CONCLUSIONS

The paper presents a concept/approach for the transition form analogue to digital broadcasting, which enables the provision not only of digital TV bouquets, but also for the realisation (as added-value) of broadband infrastructures and for the extension of the high-capacity national core networks to areas where they are currently unreachable. Building on the IP networking capabilities of the terrestrial digital video broadcasting standard (DVB-T), and by exploiting the resulting spectrum dividend (when DSO is applied) in terms of bit-rate allocation rather than in frequency allocation, it describes an architecture that exploits the DVB-T stream in regenerative configurations for the realisation of a common infrastructure that enables citizens located within the broadcasting area to access to triple-play services. The validity of the proposed DSO concept has been evaluated through a set of performance experiments that were conducted under real condition transmission/reception conditions on a prototype conforming to the architecture and design specifications.

A major future research direction under way concerns the exploitation of the discussed digital switchover architectural approach towards the realization of a fusion IP/DVB networking environment that supports both urban and rural always-on connectivity and triple-play services provision. The goal of such a fusion environment would be the realization of a unified infrastructure that mutates traditional passive urban citizens to active Information Society participants capable to create, manipulate and distribute their own content/services over a commonly exploited infrastructure.

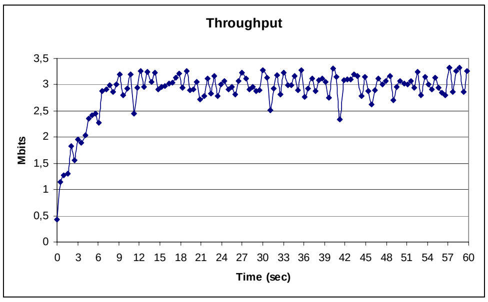

Figure 6a. Network Throughput for ADSL end user in CMN2 during unicast Internet services access – 4Mbpps allocated for IP in the common DVB-T stream.

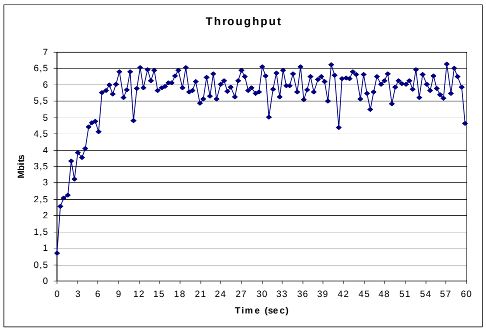

Figure 6b. Network Throughput for ADSL end user in CMN2 during unicast Internet services access – 8Mbps allocated for IP in the common DVB-T stream.

REFERENCES

[1] "Alternatives for extending broadband coverage to underserved EU regions, in the context of the Digital Divide Forum", EC Buckley study, October 2004.
[2] "Accelerating the transition from analogue to digital broadcasting", COM (2005) 204 final, Brussels, 24.05.2005.
[3] "Commission expects most broadcasting in the EU to be digital by 2010", Communication of the European Commission, IP/05/595, Brussels, May 2005(http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/05/595&format=HTML&aged=0&language=en&guiLanguage=en).
[4] http://www.dvb.org/about_dvb/dvb_worldwide
[5] E. Pallis, C. Mantakas, G. Mastorakis, A. Kourtis, V. Zacharopoulos, "Digital switchover in UHF: the ATHENA concept for broadband access", European Transactions on Telecommunications, Vol. 17 (2), pp. 175- 182, March 2006.
[6] G. Mastorakis, E. Pallis, C. Mantakas, G. Kormentzas, C. Skianis, "Exploiting Digital Terrestrial Television for Broadband access to Dispersed Locations", Proceedings of

the 1st IEEE International Workshop on ‘IP over Broadcasting Networks’ (IPBN 2006), C. Skianis (ed.), part of the IEEE ICC 2006, Istanbul, Turkey, pp. 1-4, June 2006.

[7] Prasad Calyam, Chang-Gun Lee, “Characterizing Voice and Video traffic behavior over the Internet”, International Symposium on Computer and Information Sciences (ISCIS), Proceedings published by Imperial College Press in a special edition of "Advances in Computer Science and Engineering" Book Series, 2005.

[8] G. Xilouris, G. Gardikis, E. Pallis, A. Kourtis "Reverse Path Technologies in Interactive DVB-T Broadcasting", in Proc. IST Mobile and Wireless Telecommunications Summit, Thessaloniki, Greece, pp. 292-295, June 2002.

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