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Research Article

Hybrid Terrestrial-Satellite DVB/IP Infrastructure in Overlay Constellations for Triple-Play Services Access in Rural Areas

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This paper discusses the convergence of digital broadcasting and Internet technologies, by elaborating on the design, implementation, and performance evaluation of a hybrid terrestrial/satellite networking infrastructure, enabling triple-play services access in rural areas. At local/district level, the paper proposes the exploitation of DVB-T platforms in regenerative configurations for creating terrestrial DVB/IP backhaul between the core backbone (in urban areas) and a number of intermediate communication nodes distributed within the DVB-T broadcasting footprint (in rural areas). In this way, triple play services that are available at the core backbone, are transferred via the regenerative DVB-T/IP backhaul to the entire district and can be accessed by rural users via the corresponding intermediate node. On the other hand, at regional/national level, the paper proposes the exploitation of a satellite interactive digital video broadcasting platform (DVB S2/RCS) as an overlay network that interconnects the regenerative DVB-T/IP platforms, as well as individual users, and services providers, to each other. Performance of the proposed hybrid terrestrial/satellite networking environment is validated through experimental tests that were conducted under real transmission/reception conditions (for the terrestrial segment) and via simulation experiments (for the satellite segment) at a prototype network infrastructure.

1. Introduction

Triple-play services provision depends not only on the access network that is usually considered as the last mile network, but also on the connection from the local "point of presence" (e.g., local exchange building) to the core high-capacity backbone network. This connection, which is known as "backhaul", or the "middle mile" network, constitutes a significant issue for accessing triple-play services especially in dispersed, rural, and less developed areas, that is, those that are far away from the high-capacity core network. The backhaul connection to the nearest available main network node for triple-play services provision can be currently addressed by a variety of proprietary technologies, such as fibre optical, satellite, and microwave radio links [1, 2], the cost of which is proportionally increased to the remoteness, while decreasing as the number of customers is escalated. As a result, and especially in the case of highly remote/rural communities, and/or low population areas, these technological solutions prove to be unprofitable for the services/network provider, and therefore deployment of backhaul for triple-play services provision still remains an issue in these regions.

While proprietary technologies prohibit individual investments in rural and less developed regions (and therefore backhaul connections for triple-play services access), it is foreseen that technology/services convergence could alleviate these obstacles and pave the way towards cost/economically efficient backhaul solutions. By encouraging synergetic activities among the various technology/service sectors, convergence could play a key role in the realisation of fusion environments that exploit and avail the particularities and complementarities among them, besides being fairly shared and commonly exploited by existing and potential service/network providers. In this context, the paper anticipates that convergence among the Broadcasting and Internet

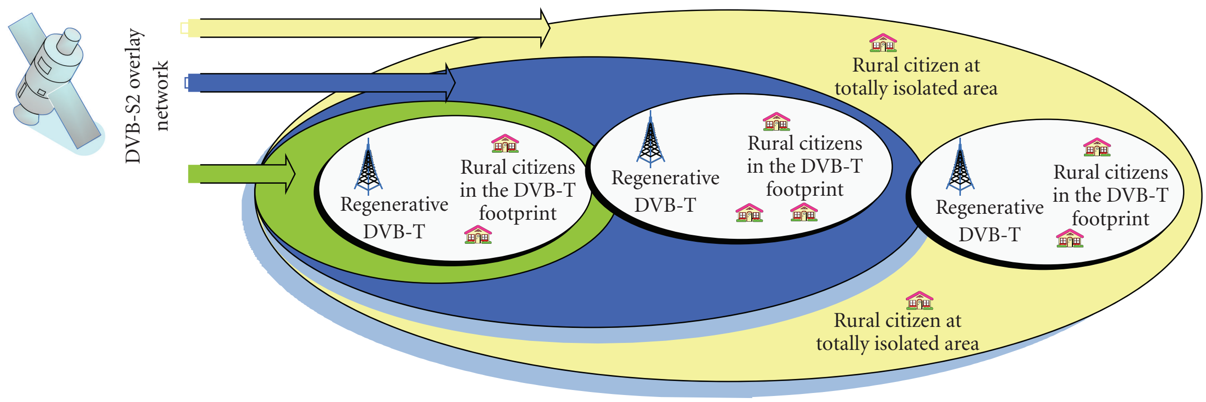

Figure 1: Overall architecture of the hybrid terrestrial/satellite infrastructure.

sectors may provide a very promising and cost-effective alternative backhaul solution. Building upon the advances of digital video broadcasting (DVB), and by exploiting their convergence with emerging wired/wireless telecommunication/Internet technologies (xDSL, WLAN, etc.), the paper proposes a hybrid terrestrial/satellite DVB/IP infrastructure capable of providing triple-play services in rural areas, at regional and national level (see Figure 1).

By exploiting the terrestrial digital video broadcasting (DVB-T) stream in regenerative configurations, it designs and implements a unified decentralised networking infrastructure at regional level, which is present and available within the entire broadcasting area. This decentralised infrastructure enables (i) urban citizens to distribute their own content/services to the entire network and (ii) with marginal cost, rural citizens to access/consume triple-play services and to be always-on connected to this unified infrastructure. More specifically, and in respect to rural citizens, the regenerative DVB-T stream acts as backhaul connection (middle-mile network) for extending the core backbone (present at urban areas) till the local PSTN/ISDN exchanger of a rural area, enabling in this way the deployment of xDSL networks as last-mile connections that provide for always-on connectivity.

Towards expanding the proposed concept at national level, the paper proposes the deployment of a number of these DVB/IP platforms at various rural areas and their interconnection via DVB-S2/RCS technology-based satellites. Exploiting the intrinsic characteristic of the DVB-S2 for carrying heterogeneous IP traffic over the same platform, the paper presents the design and implementation of a satellite backhaul connection that acts as an overlay network upon the terrestrial segments (i.e., upon the regenerative DVB-T platforms) for triple-play services provision, besides being able not only to interconnect each other but also individual citizens located at totally isolated rural areas (e.g., dispersed islands, or users outside a DVB-T broadcasting footprint).

Following this introductory section, the rest of this paper is structured as follows. Section 2 describes the overall architecture of the terrestrial segment in the proposed hybrid terrestrial/satellite infrastructure, utilizing regenerative DVB-T platforms as backhaul connections for triple-play services provision mainly in rural areas, while Section 3 elaborates on its performance. Section 4 presents the overall architecture of the satellite segment that acts as an overlay network upon the terrestrial segments, while Section 5 elaborates on its performance as a matter of system and network scalability, network throughput, and packet loss, for national/international exploitation. Finally Section 6 concludes this paper.

2. Terrestrial DVB/IP Segment

The advent of digital video broadcasting (DVB) technology and its exploitation over terrestrial links (DVB-T), along with its inherent characteristic to combine heterogeneous traffic into the same data stream (i.e., MPEG-2 and IP data) [3], presents the possibility for the creation of a converged DVB/IP networking infrastructure [4, 5], able to provide triple-play services everywhere within the broadcasting footprint. Typical DVB-T broadcast channels send megabits or tens of megabits per second in a shared and unidirectional mode. Bidirectional operation, which is required for personalised and unicast services (e.g., triple-play services), can be achieved either by making use of a centralised approach where the user is directly communicating with the broadcasting station over a return path channel [6, 7] making use of any access technology such as WLAN, PSTN, and GSM [8], or in a decentralised approach through a subsystem of distributed Cell Main Nodes (CMNs). The overall architecture of such a decentralised infrastructure is depicted in Figure 2. 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 to the specific CMN) to access IP unicast services that are hosted by the entire infrastructure (e.g., by the ISP and Multimedia provider as depicted in Figure 2). 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

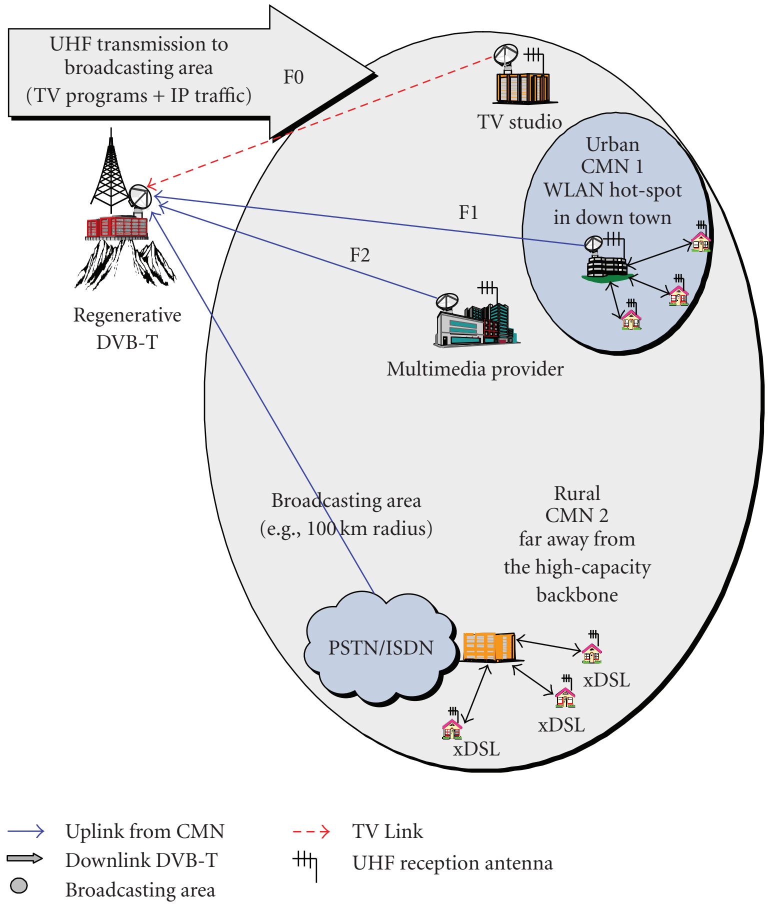

Figure 2: Overall architecture of the terrestrial DVB/IP segment.

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 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.

2.1. Configuration of the Regenerative DVB-T. The configuration of the regenerative DVB-T broadcasting point (depicted in Figure 3) is capable of (a) receiving the users IP traffic over the uplinks (via the appropriate CMN—see PSTN/ISDN uplink and F1 in Figure 2), (b) receiving any local digital TV program(s) with IP multicast and Internet services, stemming from the TV studio broadcaster and the ISP/multimedia provider, respectively (see TV Link and F2 in Figure 2), and (c) creating and broadcasting a common UHF downlink that carries the digital TV program(s) and the IP data.

According to the configuration depicted in Figure 3, the multiplexing device receives any type of data (IP and/or digital TV programs), 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, triple-play services providers contribute to the creation of a backbone (DVB-T stream) that is present and available within the entire broadcasting area. An actual exploitation of this architecture can be realized for the deployment of xDSL infrastructures that enable not only triple-play services and access, but also always-on connectivity. The deployment of xDSL access networks require the head-end unit (i.e., DSLAM) to be placed close to a high-capacity core backbone (i.e., fiber), while the end user's equipment must be located no further than a few

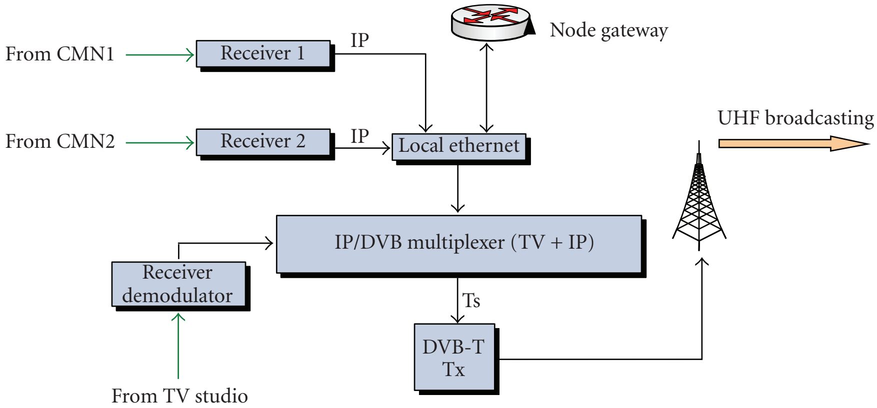

Figure 3: Configuration of regenerative DVB-T.

kilometers from the point-of-presence (i.e., 5 km from the DSLAM). As a result, in rural areas and in areas of dispersed population, that are far away from the core backbone, xDSL deployment cannot be realized unless extension of the high-capacity backbone is achieved to reach these areas. However, this is a matter of installation and operational costs.

In this context and by taking into account that DVB-T transmissions utilize coverage areas of many kilometers (e.g., 100 km) the proposed configuration (Figure 3) can be exploited for realizing the common DVB-T stream in middle-mile/backhaul configurations, extending the core backbone within the entire broadcasting area and making it available or present at any CMN within the coverage footprint. This type of networking solution, which conforms to the proposed architecture, is presented next, with a description of a rural-based CMN that is placed away from the national backbone, providing users with always-on connectivity and access to triple-play services. An urban-based CMN is also presented, enabling users to actively participate in the creation of the final DVB-T stream and provide their own content/services.

2.2. Configuration of Urban-Based Cell Main Node. Although access to triple-play services and always-on connectivity can be easily achieved in urban and developed areas (due to the widespread availability of ICT in these regions), the realization of a networking architecture constitutes a major factor in the active participation of users in the information society (in the context of not only consuming custom and predefined content) but also in the capability of creating, manipulating, and distributing their own content and services over a commonly exploited infrastructure. The active participation of these potential content and application providers (stemming from traditional, passive users) is the key to generate revenues, create rich activity in the market chain, and spearhead new progress in the broadcasting, Internet, and telecommunication sectors. The realization of a networking architecture decouples the service provision function from the network operators and offers this privilege to all potential interested players, changing the traditional passive users to active ones. In the previous context, urban users who wish to become active participants in the information society, can access the entire infrastructure for distributing their own services via a CMN (urban-based CMN), the configuration of which is depicted in Figure 4. This infrastructure utilizes a broadband uplink for realizing the communication between this CMN and the regenerative DVB-T (e.g., microwave RF link) and WLAN technology in the access network, consisting of an access point (AP) at the CMN site, which maintains a full duplex communication with the station adapters (SAs) at the users' sites. The CMN gathers all IP traffic stemming from its users (custom and active users, potential content providers, etc.), and forwards it to the central broadcasting point (i.e., regenerative DVB-T). This IP traffic is processed, regenerated and multiplexed with all other IP traffic (stemming from other CMNs) into a single transport stream (i.e., IP-plex), with the digital TV program(s) stemming from the TV broadcaster, participating in this way in the creation of the final DVB-T bouquet. In this respect, an active user exploits the common DVB-T stream for maintaining his own e-business, which is virtually present at any place within the entire broadcasting area (via the common DVB-T stream). Such an e-business may be the realization of an IP-TV multicast, capable of targeting customers in a radius of 100 km, located both in urban and rural areas.

2.3. Configuration of Rural-Based Cell Main Node. In rural areas where the population is dispersed that are far away from a core backbone network (e.g., fiber) and only custom PSTN/ISDN is currently available , access to triple play services and always-on connectivity cannot be realized, unless diffusion of ICT is achieved and/or extension of the core backbone to these regions is accomplished. Cost mainly constitutes the major obstacle for such ICT diffusion and extension of the core backbone in these areas. For these regions or cases, the exploitation of the proposed networking architecture is a very promising solution, enabling not only the provision of triple-play services but also of 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

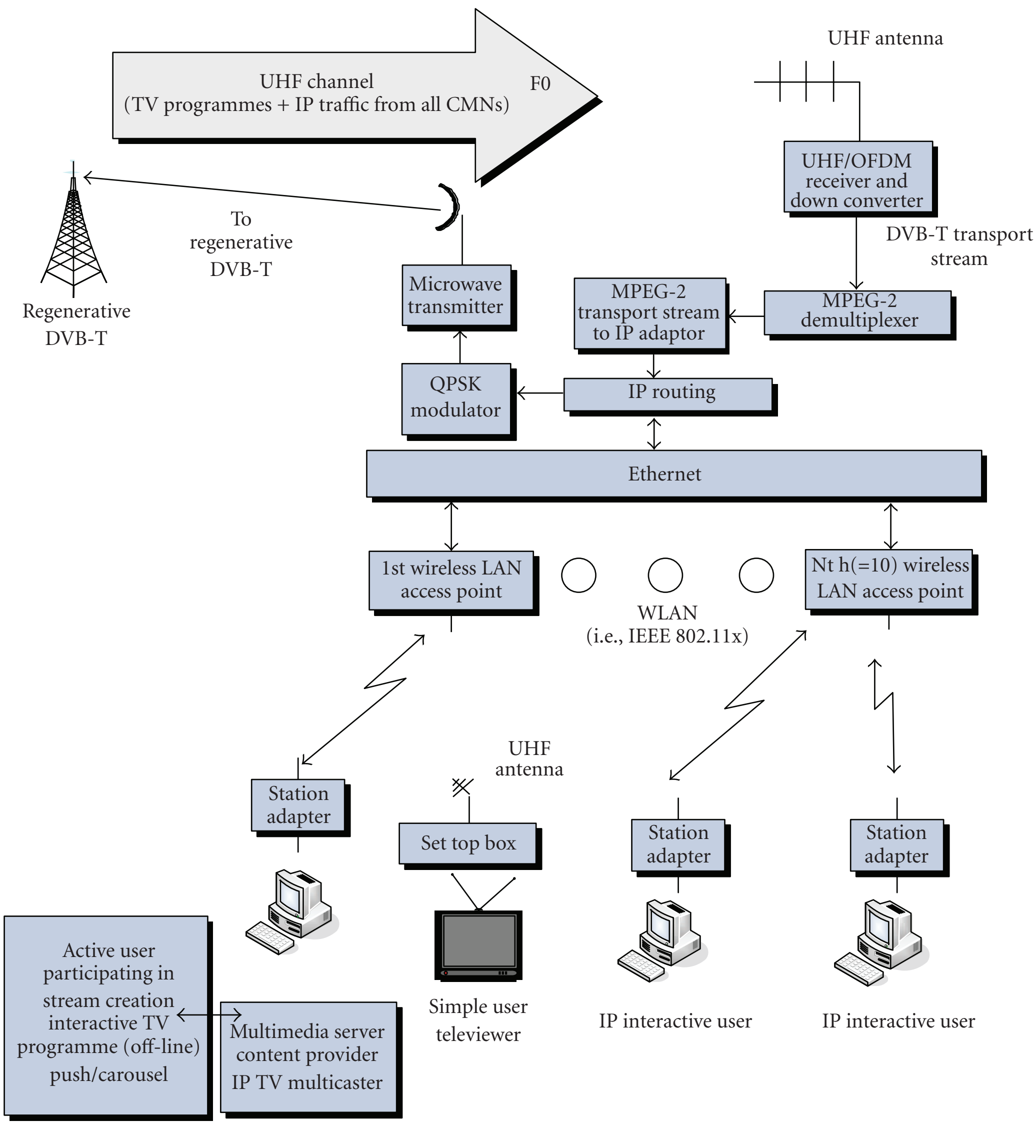

Figure 4: Urban-based CMN.

MPEG-2 and IP-TV services) to be present and available within the entire coverage area. Users located even in rural and regions, where the population is dispersed, can easily and cost effectively access services by utilizing a simple/custom UHF reception antenna and a corresponding DVB-T reception equipment on their premises. In addition, the exploitation of the common DVB-T stream in backhaul/middle-mile configurations enables the fast/immediate interconnection between the core backbone and any CMN within the entire broadcasting footprint. With such an approach, in a way, the core backbone is transferred to rural-based CMNs, enabling the deployment of ICT that provides for always-on connectivity (e.g., ADSL). The overall configuration of such a rural-based CMN is depicted in Figure 4. 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 an ADSL network, by exploiting the common DVB-T stream as a backhaul and middle-mile infrastructure, capable of interconnecting the core backbone (present in urban areas) with the rural-based CMN. Such an approach enables rural users to maintain always-on connectivity (over the ADSL network) and triple-play services access over the common UHF beam.

3. Performance Evaluation of the Terrestrial DVB/IP Segment

In order to evaluate the network performance of the proposed terrestrial system, several experimental tests were conducted by emulating the provision of bulk TCP data streams under a specific use case scenario (i.e., when a

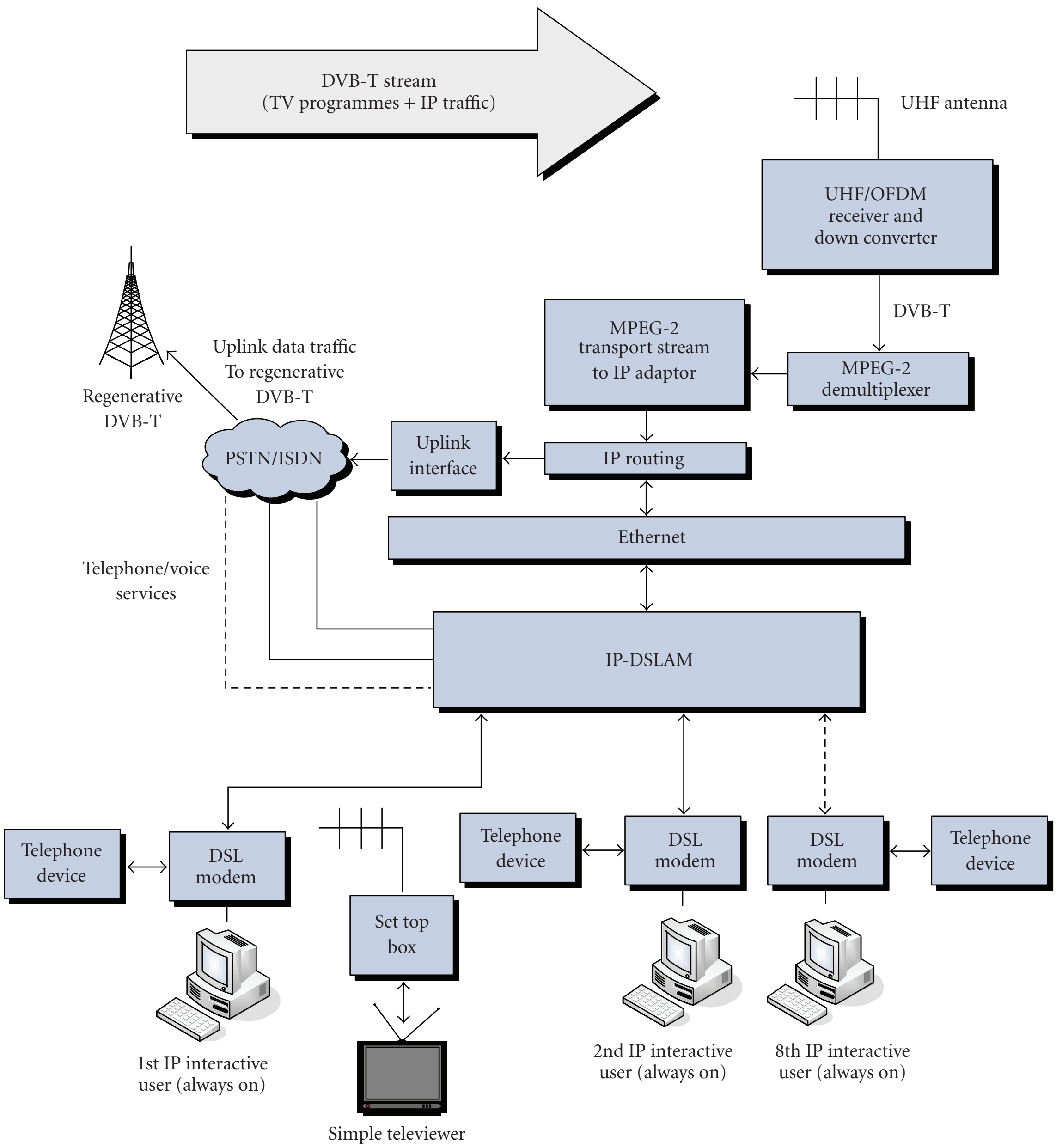

FIGURE 5: Rural-based CMN.

user located in CMN2 is accessing content hosted by an active user located in CMN1—see Figure 6). The overall system architecture regarding this preliminary experimental test is depicted in Figure 6, 8 Mbps of the total available bandwidth of the common DVB-T stream (i.e., 21.11 Mbps) were allocated for the provision of TCP/IP traffic, and the rest of the available networking resources were dedicated to provide a number of digital television programs.

During the experimental process (i.e., 180 s) Iperf application [9] was utilized to generate TCP/IP data traffic between an end user located in CMN2 and an active user located in CMN1 (see Figure 6). The reverse data traffic stemming from the end user is received by CMN2 and forwarded to the regenerative DVB-T platform, where it is then broadcasted together with multiple digital television programs. CMN1 is then able to receive this traffic and forward it to the active user's terminal. The forward data traffic and reply signals, originated from the active user, are received by the regenerative DVB-T platform through CMN1 and the IEEE802.11g uplink. This traffic is then broadcasted to the entire DVB-T coverage area, enabling CMN2 to receive the reply signals and forward them to the end user's terminal. Tcpdump application [10] was utilized, running both at the end user's and active user's terminals, for capturing the headers of the transmitted/received data packets, besides storing them as "dump" files. Upon completion of the TCP connection, the data stored within the "dump" files were collected and analysed by the TCPTrace tool [11], providing

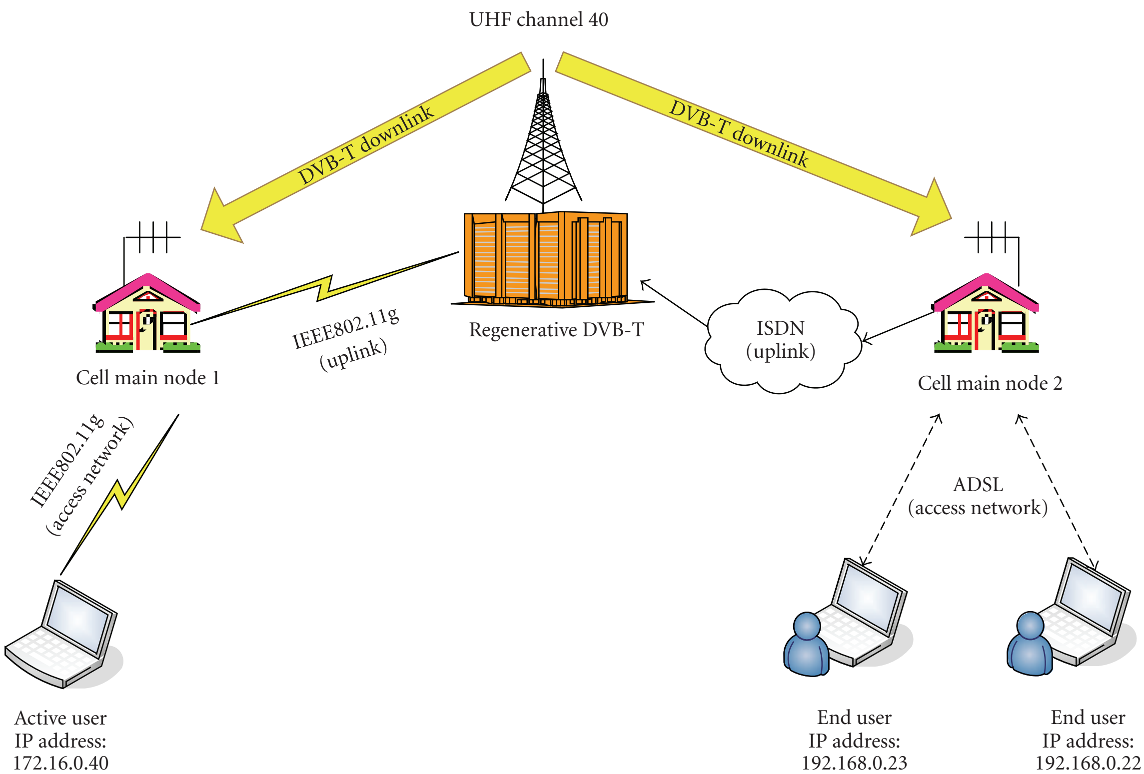

FIGURE 6: Experimental test bed.

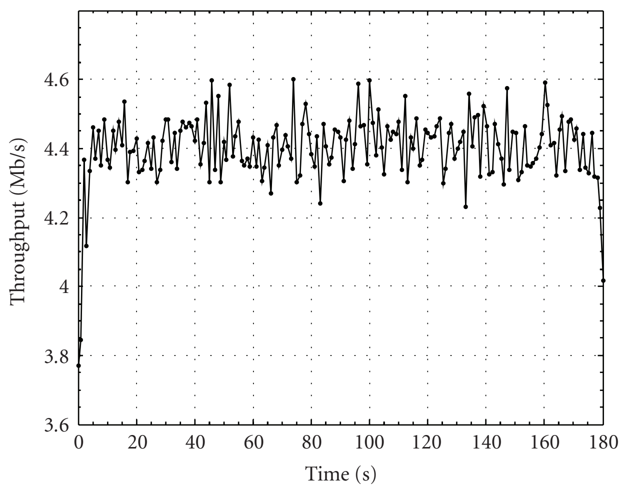

FIGURE 7: Useful throughput for end-to-end communication.

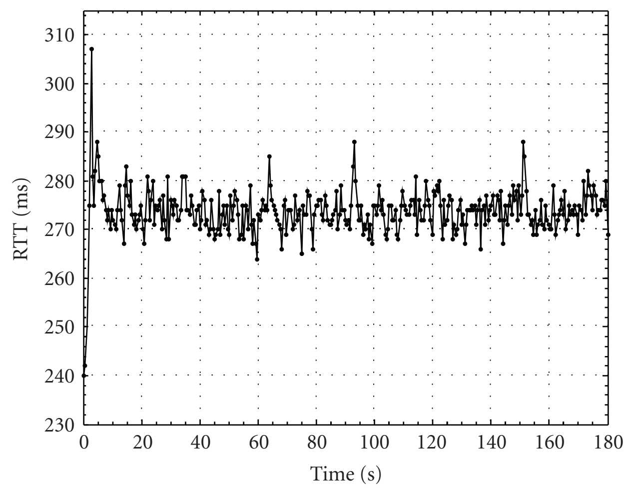

FIGURE 8: Round trip time for end-to-end communication.

results regarding the instantaneous useful throughput, TCP Round Trip Time (RTT), and retransmitted packets. The experimental results indicated an average useful throughput of 4.4 Mb/s and an average RTT of 273.69 ms, during this end-to-end TCP communication, while no retransmissions were observed. Figures 7 and 8 depict the graphical representations of useful throughput and RTT versus time, respectively.

4. Satellite DVB/IP Segment

The previous sections presented the design, implementation, and performance evaluation of the terrestrial DVB/IP segment of the proposed hybrid infrastructure, exploiting DVB-T in regenerative configurations for the realisation of backhaul connections in order to enable local/regional access (i.e., within the DVB-T footprint) to triple-play services even by rural citizens. In order to expand the proposed concept at national level, so that triple-play services would

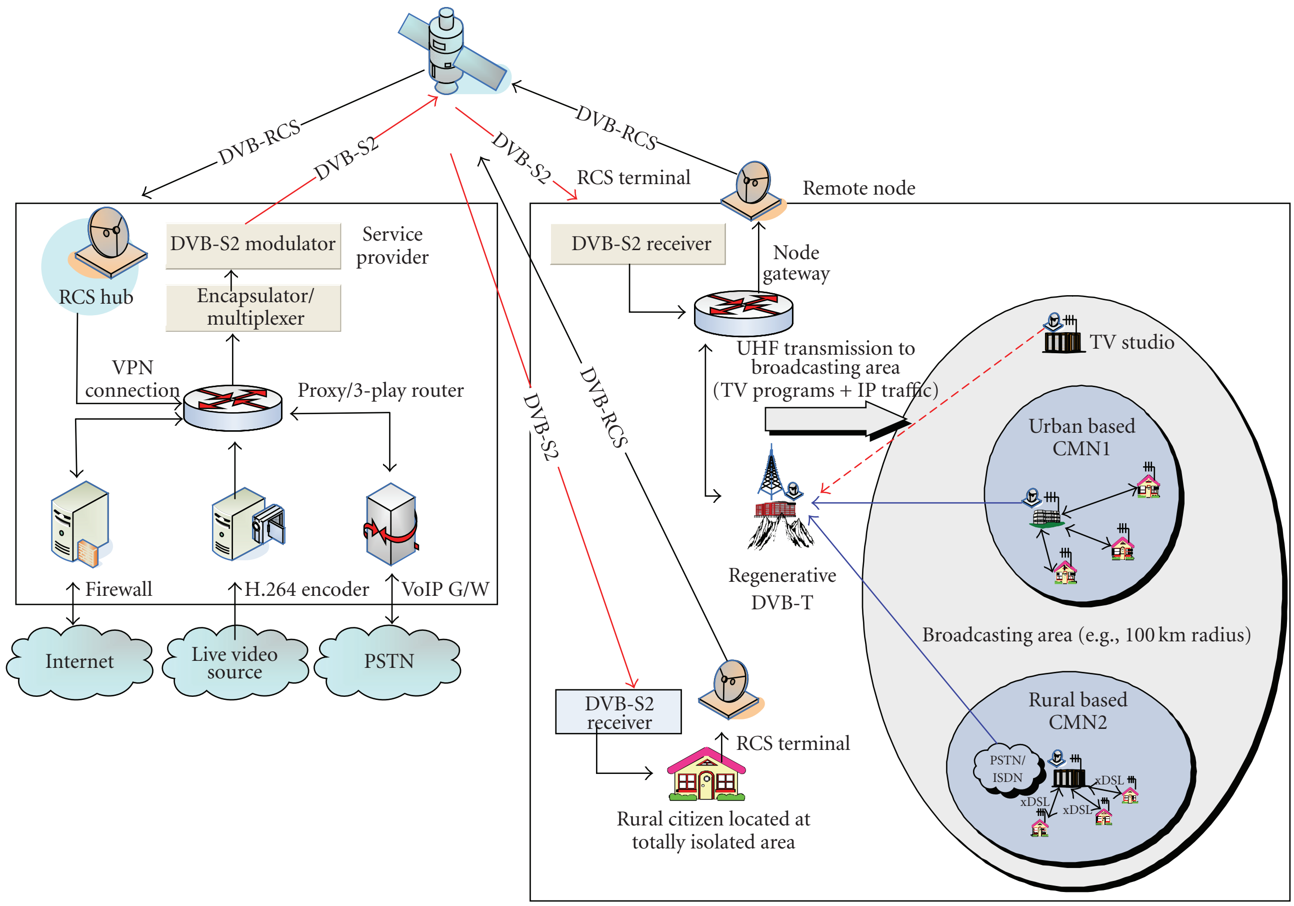

Figure 9: Overall architecture and configuration of the satellite DVB/IP segment.

be accessed by any user/citizen, a number of such DVB/IP platforms must be deployed at the various rural areas and be interconnected to each other. Towards these, DVB-S2/RCS technology-based satellites can be exploited for the creation of an overlay network upon the terrestrial segments, capable not only of interconnecting but also complementing the regenerative DVB-T coverage, especially in cases of users located in totally isolated rural areas (i.e., where no regenerative DVB-T platform exists, or users outside a DVB-T broadcasting footprint). The same holds for citizens on the move, such as passengers in trains, airplanes, or ships. For all these cases, the DVB-S2/RS satellite access solution is very promising for the delivery of ubiquitous triple-play integrated services.

The overall configuration of the satellite DVB/IP segment, depicted in Figure 9, provides a flexible and viable broadband architecture for triple-play services provision to individual users and small wired or wireless local networks which are geographically isolated or, in general, are in a condition which prevents them from connecting to terrestrial network infrastructures. The proposed system is based on a DVB-S2 communication chain (IP-to-DVB encapsulator, multiplexer, and modulator) and a remote DVB-RCS Hub (i.e., RCS Hub in Figure 9), located at the regenerative DVB-T or at individual user's premises for collecting and transmitting the uplink data. A VPN (Virtual Private Network) tunnel from the RCS Hub feeds the data into the provider platform. A Proxy/3-play Router feeds the triple-play streams (destined to the end users) to the Encapsulator for processing and transmission and routes appropriately the IP datagrams, which arrive via RCS Hub from the terrestrial sites. The Encapsulator/multiplexer operates in compliance to [12] and treats each traffic stream individually and can apply different queuing priorities to each service. This differentiation is performed in a static manner. In case that dynamic bandwidth management is required, a mechanism like the one described in [13] can be employed. Video streams are served by a real-time H.264 encoder fed by a live source, and a VoIP Gateway utilizing H.323/SIP acts as an interface to the public PSTN network. Internet connections are firewalled and served via a Web proxy.

At the remote node (e.g., regenerative DVB-T or individual user's premises), the reception and transmission is undertaken by two separate modules—a DVB-S2 receiver and a separate DVB-RCS terminal. A Node Gateway undertakes the routing and the policing of the traffic within the node. In this infrastructure (Figure 9), each regenerative DVB-T platform utilizes a DVB-S2/DVB-RCS satellite terminal, in order to be interconnected with other terrestrial segments.

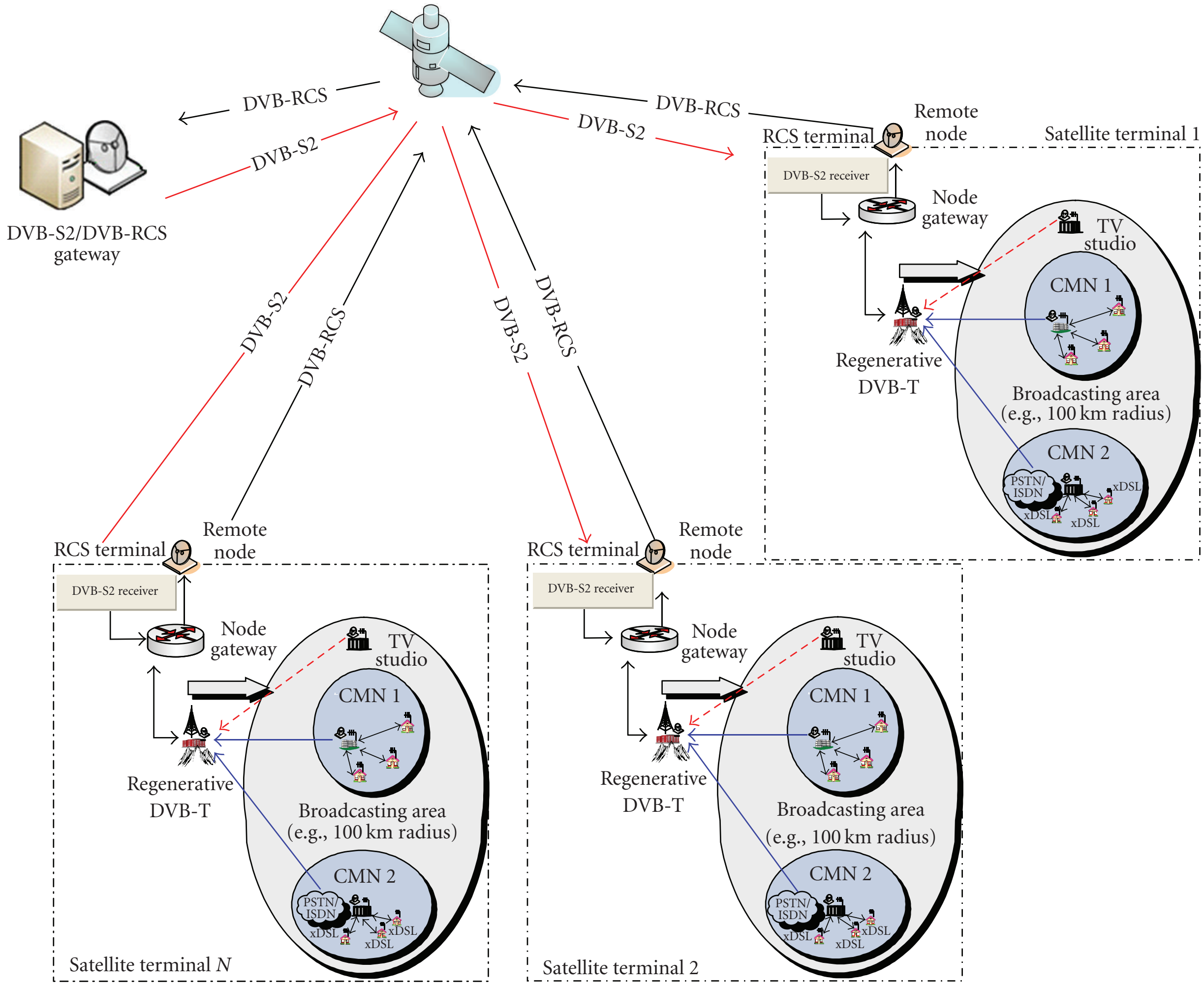

Figure 10: Configuration of the simulation test-bed for evaluating the performance of the hybrid terrestrial/satellite DVB/IP infrastructure.

IP traffic and triple-play services stemming/targeting from/to the regenerative DVB-T platforms are forwarded by the individual DVB-RCS uplinks to the satellite. The networking services, that are provided by the DVB-S.2 satellite downlink, are encapsulated into the common terrestrial television bouquet and finally broadcasted via the UHF channel at high data rates following the DVB-T standard.

5. Performance Evaluation of the Hybrid Terrestrial/Satellite Infrastructure

This section presents the scenario used to validate the capabilities and potentialities of the proposed hybrid terrestrial/satellite infrastructure, in terms of scalability and maximum number of supported terminal/nodes, network throughput, and packet loss. The simulation framework was constructed by using Opnet 11.5 [14], and the study included the core network performance of the overall system.

More specifically, the sets of simulation tests were designed in order to evaluate the performance of the uplink-downlink communication chain, which uses DVB-S2 technology in the downlink and DVB-RCS in the uplink. The overall configuration of this experimental test-bed is depicted in Figure 10.

In the first simulation scenario a shared uplink of 2 Mb/s and a downlink of 4 Mb/s were considered. By varying the signaling overhead as well as the interval between two successive signaling packets, the maximum number of supported satellite terminals was obtained (see Figure 11). It should be noted that during these simulation experiments “satellite terminal” was considered the reception/transmission modules both at the regenerative DVB-T terrestrial segments, and at individual user’s premises. Following the simulation results it was verified that for the recommended signaling overhead (5% of the total bandwidth) and for an interval between two successive signaling packets of five seconds (which presents a good trade-off between reactivity and overhead), a maximum number of 1736 satellite terminals can be supported.

In Figures 12 and 13 the average throughput and the packets loss are, respectively, presented in relation to the number of multimedia flows. In these simulations, the scalability and efficiency are emphasized by using variable number of multicast multimedia MPEG-4 communication

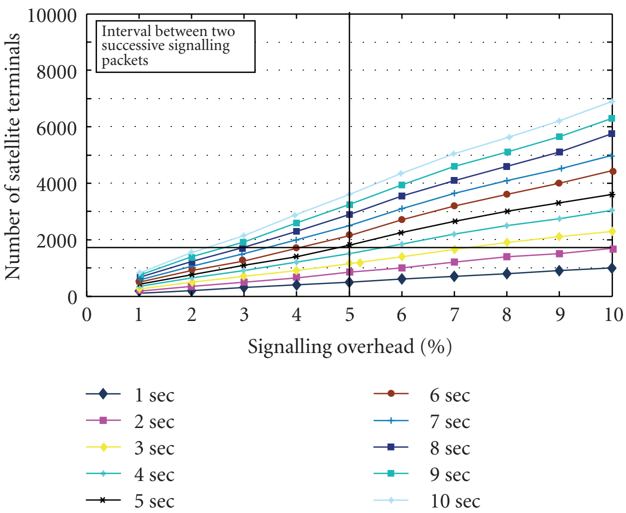

FIGURE 11: Scalability of the proposed framework in terms of supported terminals.

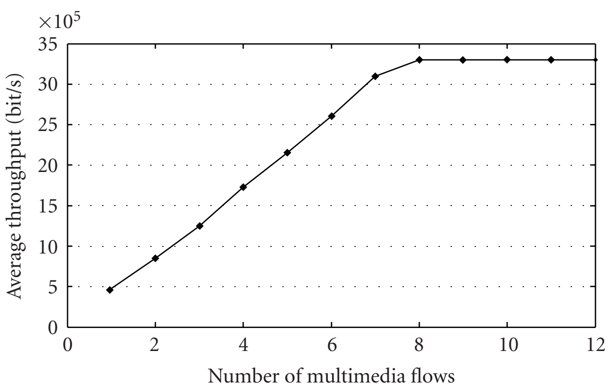

FIGURE 12: Average throughput versus number of multimedia flows.

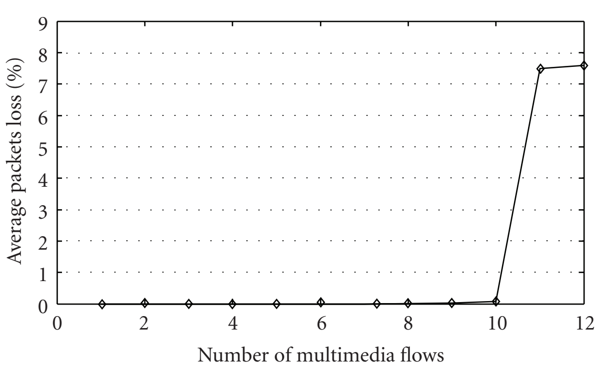

FIGURE 13: Average packets loss versus number of multimedia flows.

sessions (the average bit rate is about 480 kb/s). It is clearly shown in Figure 12 that the proposed configuration supports a maximum number of 10 parallel sessions. For this number of sessions, throughput is maximized (as it is observed in Figure 13) and the packets loss is insignificant ($\ll$ 1%). However, additional flows impact very badly the system. Indeed, the loss ratio increases rapidly to value greater than 7%, which deteriorates the perceived quality of service.

6. Conclusions

This paper elaborated on the convergence of digital broadcasting and Internet technologies, by designing, implementing, and evaluating the performance of a hybrid terrestrial/satellite networking infrastructure, enabling triple-play services access in rural areas, both at local and national levels. At local/district level, the paper proposed the exploitation of terrestrial digital video broadcasting platforms (DVB-T) in regenerative configurations in order to create terrestrial DVB/IP backhaul between the core backbone (present in urban areas) and a number of intermediate communication nodes distributed within the DVB-T broadcasting footprint (in rural areas). Triple-play services, that are available at the core backbone, are transferred via the regenerative DVB-T/IP backhaul to the entire district (DVB-T coverage area) and can be accessed by rural users/citizens via the corresponding intermediate node, utilising broadband technologies only in the access network (e.g., WLAN, xDSL). At regional/national level and in the case of totally isolated users (e.g., located outside a regenerative DVB-T footprint), the paper discussed the exploitation of satellite interactive digital video broadcasting platform (DVB-S2/RCS) as an overlay network that interconnects the terrestrial DVB-T/IP platforms (located within the DVB-S2 footprint), as well as individual users, services providers, and ISPs to each other. Performance of the proposed hybrid terrestrial/satellite networking environment verified the validity of the proposed architecture, through experimental tests that were conducted under real transmission/reception conditions (for the terrestrial segment) and via simulation experiments (for the satellite segment) at a prototype infrastructure that conforms to the proposed architectural design issues.

Acknowledgments

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