Broadband Data Access over Hybrid DVB-T Networks

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Abstract. **Contemporary DVB-based digital terrestrial systems (DVB-T, DVB-H) provide an efficient distribution network not only for DTV programs, but also for interactive data services. When combined with an appropriate interaction network (return channel), the DVB platform can act as the downlink in a hybrid asymmetric network, enabling for bidirectional broadband data access, supporting Internet connectivity and client-server applications. In this context, this paper presents an interactive DVB-T platform based on various uplink technologies, and validates the performance of each configuration in data communication.**

Keywords: **Interactive broadcasting, TCP, DVB-T, asymmetric networks, hybrid access**

1. Introduction

The widespread adoption of the DVB-T technology has promoted the role of this digital terrestrial television system as tomorrow's leading carrier for digital broadcast services. The capability of insertion of IP data services within the transmitted MPEG-2 stream multiplexed with digital television programs has added the perspective of DVB-T being used as a broadband downlink channel offering high-speed data access to both stationary and mobile end users. Furthermore, the recent emergence of the DVB-H (DVB for Handheld) as an extension/improvement to DVB-T, aims to adapt the digital broadcasting technology more to the needs of IP datagram transmission. By adopting an additional Forward Error Correction layer and a time-slicing mechanism for energy saving, DVB-H offers a promising solution for broadband data access for handheld terminals.

The DVB-T/DVB-H specifications refer to a unidirectional transmission medium (as with any broadcast platform) on which the integration of traditional TCP/IP services within the DTV multiplex requires an additional "Interaction Channel" acting as an uplink and conveying traffic from the user back to the service provider. A hybrid asymmetric network is thus formed, whose generic topology has been specified by ETSI in [1]. This concept can lead to several convergence scenarios among

DVB-T/DVB-H and data communication networks, including wireless and cellular systems, thus achieving net data rates orders of magnitude higher than those networks alone [2].

This paper analyzes the behaviour and performance of TCP within such a hybrid system under various uplink implementations (PSTN, ISDN, 802.11/802.11b, GSM data, GPRS) and demonstrates how relatively high values of TCP throughput can be achieved even when using narrowband interaction networks for the uplink traffic. Specifically, section 2 discusses the network topology of the testbed used in our experiments. The results of the various uplink implementations, i.e. PSTN/ISDN, WLAN, GSM/GPRS are presented in Sections 3,4 and 5 correspondingly. Finally, Section 6 concludes the paper and presents subjects for future research.

2. Testbed configuration

As standardised in [1], an interactive DVB network consists of two discrete parts: the Broadcast and the Interaction channel. In the DVB-T case, the downlink TCP/IP traffic is encapsulated into an MPEG-2 compliant Transport Stream by an IP-to-DVB Gateway and transmitted by a COFDM Modulator according to the DVB-T specification [3]. IP-to-DVB encapsulation follows the MPE (Multi-Protocol Encapsulation) method. The broadcast data are received at the end user's side by a "Broadcast Interface Module", a DVB receiver either in a stand-alone (set-top box) or in an add-in card form. The client computer sends back data through the uplink utilising its "Interactive Interface Module" which is the interface to the uplink network (e.g. a modem in the case of PSTN interaction). The network of the broadcaster/service provider is also equipped with an interface to the Interaction Network and its IP backbone topology must be configured to ensure asymmetric TCP data flow where the useful data are sent through the broadcast channel (DVB-T) and the requests and acknowledgements return via the Interaction Network in case of data downloading.

The generic configuration adopted in this paper is presented in Fig. 1.

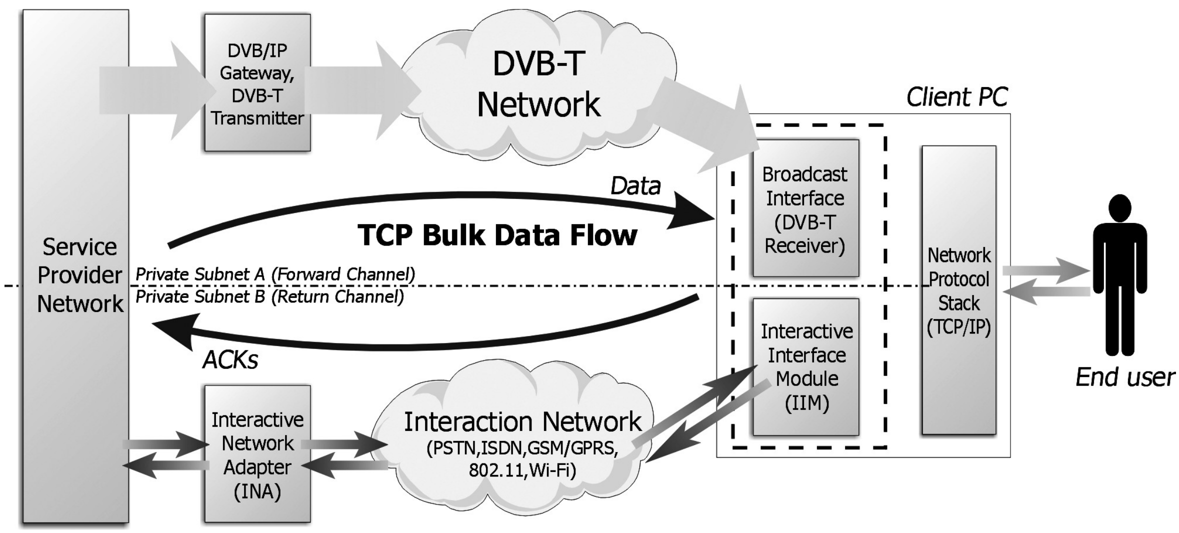

Fig. 1. Interactive DVB-T Network for asymmetric TCP data exchange

In the laboratory-based testbed implemented, the end user equipment is integrated in a single host, a typical Windows-based PC with a PCI DVB-T receiver card. At the service provider side, a Linux host is used as the data server. The DVB-T transmitter was configured at QAM-64 modulation, 5/6 convolutional code rate and guard interval equal to 1/4 of the symbol period, resulting in useful downlink rate of almost 25 Mbps. The behaviour and performance of TCP was tested during a 60-second bulk data transfer from the data server to the Client PC generated by Iperf [4]. The dump files generated in the data server after monitoring its network interface during the data exchange period were analyzed by TCPTrace [5] to obtain information regarding the TCP throughput, the round-trip times, the amount of unacknowledged data on the network at any moment, and the advance of the data and ACK sequence number during the transmission.

For the Interaction Network, several technologies were considered, from common PSTN and ISDN communication to wireless network technologies (IEEE 802.11/802.11b) and cellular devices (GSM/GPRS). The following sections briefly present the set-up of each configuration and the results obtained for the asymmetric TCP bulk data flow.

It is important to note that no special configuration or protocol stack modification is required at the client host to operate in the interactive DVB-T network. Nevertheless, the delay introduced by both the interactive network and the DVB-T processing modules, combined with the high capacity of the DVB downlink, can sometimes result in relatively high bandwidth-delay products. It is therefore almost always necessary to adjust the maximum receiver TCP window at the client PC to ensure optimum performance. This paper presents the relationship between receiver TCP window and net throughput for each configuration.

3. The PSTN/ISDN configuration

The implementation of the reverse channel via the public switched network provides a cheap and easily accessible solution for stationary users. A common home Internet connection can thus boost its TCP download performance up to forty times, utilising the existing TV receiver installation.

A standard analogue (PSTN) or digital (ISDN) modem is used as Interactive Interface Module, and the uplink data flow via a circuit-switched connection through the public network to a PSTN/ISDN dial-up server acting as Interactive Network Adapter at the service provider network.

Preliminary validation of the network configuration include a series of ping-based RTT measurements, with the ICMP echo request directed to the data server through the public switched network and the echo reply returning via the DVB-T downlink. The results are almost independent of the ping buffer size (the size of the ICMP packet) and are displayed in Fig.2.

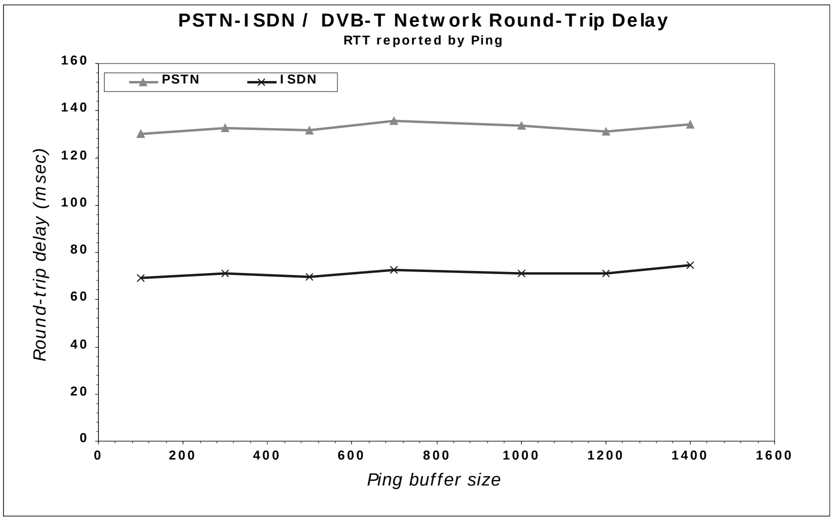

Fig.2. Ping RT times for the PSTN/ISDN-based configuration

It must be noted that the delay (mostly due to processing and buffering) of the DVB-T chain is about 40 msec. For the PSTN connection a 56K link was established, while in the ISDN case a single-channel BRI connection (64K) was used.

The combination of a relatively high delay value with the multi-megabit capacity of the DVB-T link classifies this hybrid configuration in the “long-fat network” (LFN) case. It is thus natural that the TCP throughput for a bulk data download session is highly dependant on the TCP window size of the receiver. This effect is more observable in the satellite-based DVB-S/PSTN configuration, where even higher round-trip times are observable due to increased propagation delay [6].

Fig.3 shows the average throughput in kbps over a 60-second bulk data download from the data server to the client for various receiver TCP window sizes (8, 16, 32, 64, 128, 256 and 512K). For sizes greater than 64K, the Window Scale option described in RFC 1323 is used.

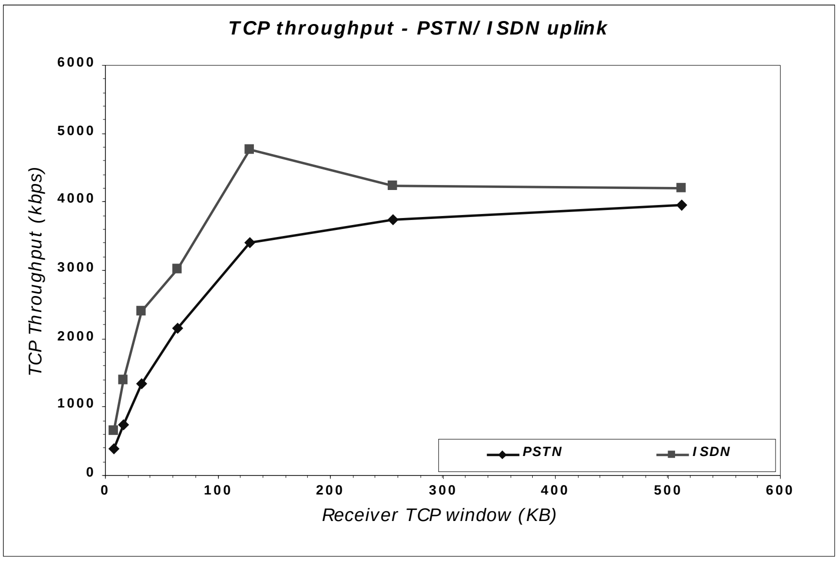

Fig.3. TCP throughput for the PSTN-ISDN/DVB-T network

The above graph shows that bit rates of almost up to 4 Mbps can be achieved with a common 56K PSTN connection. TCP throughput increases linearly with the increase of TCP window – as expected – while the round-trip delay allows for more outstanding (unacknowledged) data on the network. The throughput increase becomes “saturated” for window sizes over 128K, as the download rate is restricted from the upper bound in the ACK flow via the PSTN/ISDN uplink (56 and 64K respectively).

The fall in TCP throughput at window sizes greater than 128K in the ISDN case is also noteworthy. Traffic analysis performed on the TCP connection shows that, with large window sizes, the increase in the amount of unacknowledged data causes constant accumulation of ACKs in the uplink, exceeding the capacity of the ISDN channel. At frequent intervals, a buffer overflow occurs, resulting in a whole range of ACKs being lost. The sender falsely assumes that the data were dropped in the downlink, and performs retransmissions, halving at the same time its congestion window. This periodic activation of the TCP congestion avoidance mechanism results in a significantly lower overall throughput value.

4. The WLAN configuration

The second scenario involves a wireless LAN cell as Interaction Network. A WLAN Wireless Bridge is used as IIM and an Access Point as the INA at the service provider network. The WLAN Standards IEEE 802.11 and 802.11b are examined, achieving maximum uplink rates of 3 and 11 Mbps respectively. Although modern broadband wireless data networks, including 802.11g and WiMAX provide sufficient capacity for the average user, which is comparable to that of the DVB-T channel, the WLAN/DVB convergence scenario could result in novel composite service solutions for portable users which are within both a WLAN hot-spot and the DVB-T coverage area [7].

The IEEE 802.11 devices follow the FHSS (Frequency-Hopping Spread Spectrum) scheme and are configured to operate at their maximum rate (3Mbps), while the 802.11b cell operates on the DSSS (Direct Sequence Spread Spectrum) technique.

RTT results of the hybrid network are depicted on Fig.4. The additional delay inserted by the wireless network, especially in the 802.11b case, is in the order of a few msec and is negligible when compared with the delay of the DVB-T chain.

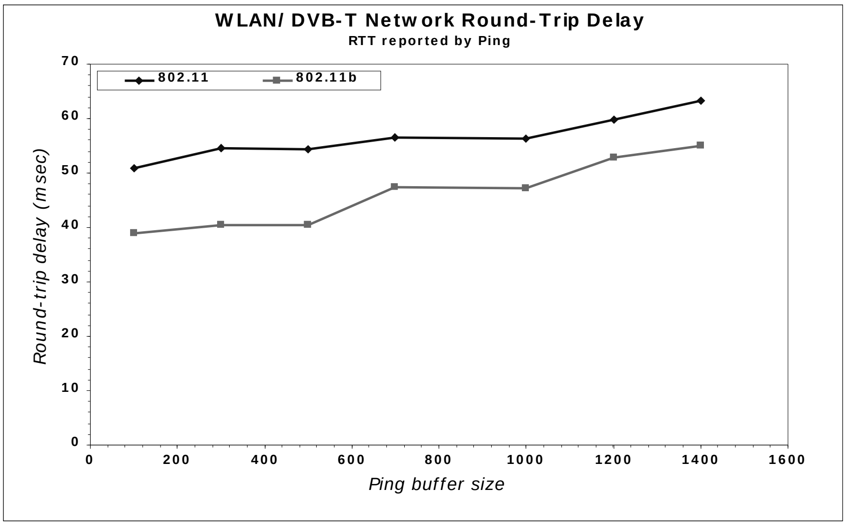

Fig.4. Ping RT times for the WLAN-based configuration

The sufficient capacity in the uplink results in relatively high TCP throughput values (Fig.5). Even high downlink rates (17 Mbps) correspond to uplink traffic of almost 500 Kbps, which is far below the WLAN capacity. That explains the absence of the saturation effect observed in the PSTN/ISDN based implementation at large TCP window sizes.

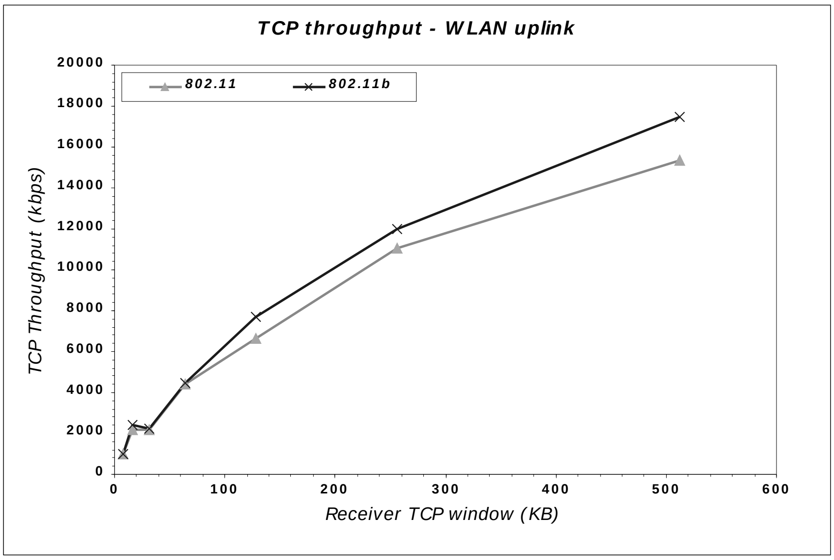

Fig.5. TCP throughput for the WLAN/DVB-T network

It must be however noted that although the WLAN capacity is sufficient for the ACK traffic, the packet rate required seems to exceed the limits of the wireless devices, as shown in Fig. 6. The values in the table are derived through a per-packet traffic monitoring, throughout the entire TCP connection in both the sender and the receiver (802.11b/DVB-T configuration). A significant loss of ACK packets is observed at high throughput rates.

TCP receiver window	**128K**	**256K**	**512K**
Uplink load (kbps)	171	266	394
Uplink load (packs/sec)	325	503	746
% of ACKs dropped	0.0	3.1	44.9
No. of retransmissions	0	0	0
TCP throughput (kbps)	7725	12013	17745

Fig.6. Uplink performance in the 802.11b/DVB-T setup

It is fortunate that even the high ACK loss percentage of 44.9% observed in the 512K case does not cause even a single retransmission of a data packet by the sender. A more careful examination of the time-sequence graph shows that the acknowledgement packets which are lost are diffused throughout the ACK stream and are not dropped in bursts. Therefore, ACKs which arrive intact contain sequence numbers that cover the dropped packets which preceded before a timeout occurs in the sender.

5. The GSM/GPRS configuration

The adoption of the mobile cellular technology to serve as Interaction Network in the hybrid DVB-T topology provides a viable, affordable and very effective solution for providing high-speed data access to portable and mobile users. The simplest scenario involves a GSM data connection, where a cellular phone acts as Interactive Interface Module at the Client PC. A 9.6 kbps circuit-switched connection takes place between the IIM and the INA (a common dial-up server in this case) through the public PLMN and PSTN networks [8]. The adoption of such an asymmetric set-up can result in a throughput rate of more than 700kbps with a single GSM connection, as it will be shown later.

The GPRS case seems more attractive, as it can support an “always-on” connection. The uplink packets are sent through the mobile phone (IIM) to the PLMN, and from there via the GGSN to the Internet and finally to the INA, which in this case is a plain Internet gateway. In this case, no circuit-switched connection takes place in the Interaction Network, as it did in the GSM-based configuration. Such an implementation, however, introduces technical difficulties, as the ACK stream generated by the Client host must traverse the mobile operator firewalls and gateways, which are normally configured to allow an entire conventional (i.e. bidirectional) TCP connection, and not the ACK-branch alone. The result is that even though a ping round-trip may be possible (provided that the intermediate firewalls are configured to permit ICMP traffic) an asymmetric TCP connection is very highly to be blocked. This is the reason why a technique needs to be adopted to overcome this restriction.

A workaround which was tested and whose proper operation was validated, is the establishment of an IP tunnel between the client and the data server along the entire Interaction path. Two Linux-based gateways running the OpenVPN suite [9] were integrated in the hybrid network, one interfacing the Service Provider network with the Internet, and the other bridging the Client PC with the IIM (mobile phone).

OpenVPN was configured to use non-encrypted UDP tunnels, which, compared to encrypted communication, are of more interest inside a GPRS connection because of the underlying security. TCP acknowledgement segments are encapsulated into UDP packets which can more easily traverse the operator firewalls. This process made asymmetric TCP connection possible, but raised the RTT to about 2 seconds for large packets (Fig.7)

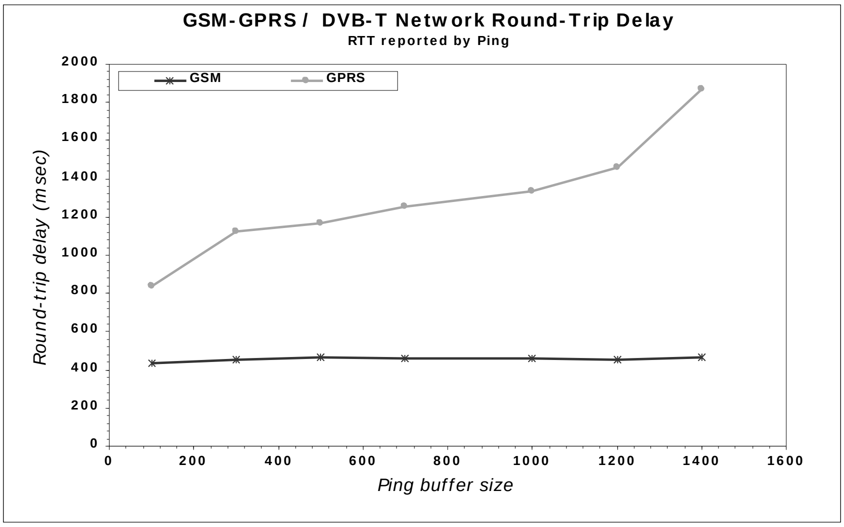

Fig.7. Ping RT times for the GSM- and GPRS-based configuration

Again, the approach of increasing the receiver TCP window can be followed to compensate for the high delay values. The useful download throughput raised by increasing the window size, as expected, but quickly comes to saturation because of the restricted uplink rate (Fig.8).

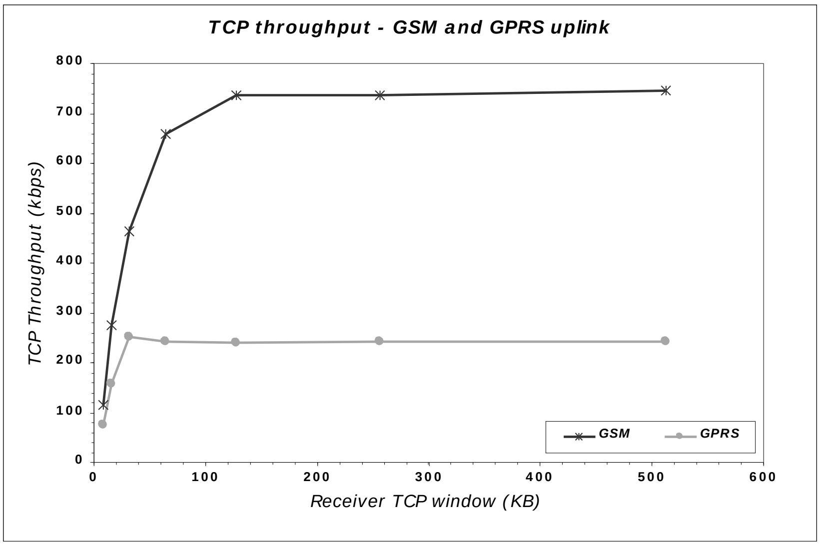

Fig.8. TCP throughput for the GSM - GPRS/DVB-T network

It must be noted that all figures regarding the GPRS performance are only indicative, since the capacity of the GPRS channel is dependant upon various parameters, mainly on the signal quality and the traffic intensity within the GSM cell. It is interesting, however, that an "always-on" connection reaching almost 250kbps of useful downlink rate were achieved even with poor reception conditions and only one GPRS timeslot allocated for the uplink, as the network monitor of the mobile phone reported. GSM data performance is significantly higher (up to 750kbps for a window size of 128K – outclassing even actual 3G rates) and more stable, due to smaller delay and effective compression of the ACK packets, but the price to pay is the costly circuit-switched connection, which remains up even when no data are being exchanged.

6. Conclusions - Future perspectives

The effectiveness and flexibility of the proposed architecture can be further expanded if the hybrid interactive DTTV network is enriched with emerging technologies in telecommunications and data networking. The standardization of DVB-H is expected to have a great impact in the exploitation of DTV systems for data transmission. Its features, including the 4K FFT mode and the FFT interleaver along with the additional FEC layer are ensuring signal robustness in the case of mobile reception [10], while its time-slicing function enable for better energy efficiency. Candidate applications for handheld DTT hybrid networking, include Interactive TV, on-demand and prefetched download of audiovisual content, TV shopping and notification-triggered TV [11].

Regarding the IP/DVB encapsulation method, the MPE (Multi Protocol Encapsulation), which is until now widely adopted and used in this paper, is very likely to be gradually replaced by the simpler and more effective IETF-designed ULE (Ultra Light Encapsulation) which offers a more direct adaptation solution, suitable for both IPv4 and IPv6 [12]. ULE is currently in the "Internet Draft" phase.

As for the interaction channel, the gradual dominance of 3G terminals make the 3G-DVB synergy a very promising scenario. Since 3G offers satisfactory bandwidth for downloading and Internet access when compared with 2G and 2G+ connections, the deployment of hybrid 3G/DVB-T/-H solutions open the perspective of novel applications, combining portable reception of high-quality broadcast audiovisual content with broadband interactivity.

This paper presented the results of measurements on the performance of TCP over an asymmetric Interactive Digital Terrestrial Television Network. Several Interaction Channel technologies were considered, illustrating the benefits of DVB-based hybrid data networks. The measurements were derived from fully functional "real-world" testbeds and show that narrowband access technologies like PSTN or GSM can be utilised at a very low cost and, when combined with the robust DVB-T broadcast downlink, can result in download rates equivalent to those of broadband wireless data networks. The future adoption and application of DVB-H featuring ULE/IPv6 support is expected to produce results of similar performance, offering at the same time greater flexibility and tighter integration with portable terminals. A viable and affordable solution for high-speed data access to mobile and stationary end users is thus provided.

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