MIPv6 Extensions for seamless IP Mobility in Converged DVB-T/WLAN Networks

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***Abstract*— The tremendous interest received by Internet applications over the last decade, on one hand, and the emergence of the digital switchover, transition from the analogue to the digital TV, on the other hand, convey the trend for the convergence of broadcasting and IP-based networks. Permitting the access to IP services inside a broadcasting context already represents an evolution in next generation of services for digital television. Furthermore, the development of a mobility support for IP users inside such an environment stands as an important enhancement, especially since wireless communications have taken a significant place into the networking world. In this paper, we propose a solution for achieving seamless mobility of IP users in a hybrid IP/DVB context, based on a network layer approach and supporting multicast. This work has been accomplished within the framework of the IST-funded European project ATHENA[1].**

***Index Terms*— Convergence of Networks, Digital Broadcasting Video, Internet Protocols, Mobility**

I. Introduction

A recent technological trend is the co-operation and integration of IP core networks with wireless access ones, especially cellular (UMTS, WLAN) and broadcast-based (DVB).

Convergence of broadcast networks, such as DVB, and IP wireless networks represents undoubtedly one main evolution in next generation of services for digital television and Internet applications. Making combination of those two technologies will not only give users easy access to much more services but also to powerful interactivity anywhere and anytime.

As a matter of fact, achieving convergence of heterogeneous wireless networks is not a simple task. Since we are dealing with wireless technologies, one important concern is on the mobility part, assuring service continuity while the user is roaming between heterogeneous networks.

On the other hand, the Digital Video Broadcasting standards provide a relatively high bandwidth data channel but it is only unidirectional. Mobile multimedia terminals require also a also a return channel through different techniques. Future evolution on portability and mobility has also effects on use and performance of Internet protocols. Mobile IP in IPv4, but especially in IPv6, offers solution to handle mobility at a network protocol layer.

In this paper, we first present the architecture of a powerful DVB-T environment designed to inter-operate with Internet protocols for efficient support of IP communications and services. This architecture has been elaborated within the framework of the IST-funded European project ATHENA. The ATHENA context is a broadcasting environment using a Regenerative DVB-T approach for developing a common infrastructure to digital TV viewers and IP users. A real IP/DVB convergence is hence achieved, through the deployment of a Regenerative DVB-T Central Broadcasting Point (CBP) transmitting multiplexed flows to the whole Broadcasting Area and Cell Main Nodes (CMN) providing the uplink channel and the delivery to IP Local Area Networks. Within this inter-working context, we propose efficient mobility support for IP users performing handovers inside this hybrid IP/DVB-T environment. Our solution takes into consideration known mechanisms such as Mobile IP and provides a support for multicast, essential for the most requested multimedia services, to which any type of broadcasting environment is dedicated.

The paper is structured as follows. Section 2 relates all the existing work on the domain. Section 3 presents the ATHENA concept of IP/DVB-T inter-working environment. Section 4 exposes our solution for achieving seamless IP mobility in a DVB environment. Section 5 focuses on the development stage and section 6 brings out the conclusion.

II. Background and Related Works

A. IP over DVB

Digital Video Broadcasting [1] is designed to be the standard for broadcast transmission over Terrestrial, Satellite or Cable link. It is known to have a very high degree of efficiency regarding transmission robustness, simplicity and spectral efficiency in the broadcast scenario. On the other hand, DVB does not provide any radio resource management facilities; it cannot dynamically assign channels to individual

[1] This work has been partially performed within the context of the IST European research project ATHENA: www.ist-athena.org

receivers. Since the radio system is by design downlink only, resource negotiation and any form of QoS control need to be performed via a second uplink-capable radio system.

The DVB-T [2] standard has first been designed to provide terrestrial broadcasting of MPEG-2 coded TV signals. But with the emergence of Internet multimedia applications, the integration of digital television standards and Internet protocols based services became an evolutionary step. Transporting IP over MPEG-2/DVB can be done in several ways depending on applications, bandwidth and reliability needs:

- **Data Piping:** In this encapsulation mode, the IP fragments are directly packed in the payload of TS packets. The payload of a transport packet can contain only one IP packet (or fragment). The data piping is rarely used for IP streams due to IP packets delimitation problems and bandwidth wasting.
- **PES Encapsulation Data Streaming:** This protocol uses "PES" (Program Elementary Stream) encapsulation of IP packets. Organization of PES into transport packets complies with the ISO/IEC 13818-1 (MPEG-2 system) standard.
- **Multi-Protocol Encapsulation (MPE):** The Multi-Protocol Encapsulation framework is the more widespread IP over DVB encapsulation protocol. This protocol has the advantage of being highly flexible. Within MPE, the multiplexer encapsulates a single IP packet into a single MPEG-2 section regardless the IP packet size.
- **Ultra Lightweight Encapsulation (ULE):** ULE is the new encapsulation method that is currently developed by the IPDVB IETF Working Group [3]. The aim of ULE is to progressively replace MPE due to (1) the overhead considerations, and (2) to introduce more evolving mechanisms for multicast management, IPv6 encapsulation, auto-configuration, etc. The principle of the ULE encapsulation is based on PDUs (Protocols Data Unit). They represent packets from different network protocols (IP datagram, Ethernet Frame, LLC/snap frames, etc…).

B. *IP Mobility*

Mobile IP is the key protocol to enable mobile computing and networking at the network level. This protocol has been specified by the IETF for IPv4 [4] and IPv6 [5].

The main goal of both the Mobile IPv4 and the Mobile IPv6 protocols is to allow a Mobile Node (MN) to continue communicating with its Correspondent Nodes (CNs) during its movement. The MN can move from its home network to a foreign network without changing its configuration. Each MN is identified by a permanent unicast IP address named Home Address (HoA) in the home network. When the MN moves to a new IP network different from the home network, it gets a new temporary unicast address that is routable within the new foreign network. This second address is called a Care of Address (CoA). To form this second address, the MN may use either stateless or stateful address configuration mechanisms with Duplication Address Detection (DAD) methods [6]. The MN repeats this operation whenever the handover occurs. The handover is a change in MN's point of attachment to the Internet such that the MN is no longer connected to the same IP subnet as it was previously.

In order to maintain the transport and higher-level communications when moving, the MN maintains its HoA and uses the CoA for routing purpose. A *binding* associates these two addresses on both the MN part and the home network part. Both the MN and the Home Agent (HA) learn and cache the binding whenever the MN's CoA changes. To do so, the MN registers its CoA with its HA. The HA may be a router on the home network. While the mobile node is away from its home link, the HA is responsible for forwarding data addressed to the MN's HoA. The signaling mechanism used during the registration of the CoA differs from the Mobile IPv4 to the Mobile IPv6 protocol. The registration on the Mobile IPv6 protocol is direct (without third-party dependency), whereas in the Mobile IPv4, it may be direct or through a new architectural entity called a Foreign Agent (FA). The FA is an IPv4 router located on an MN's visited network, which provides routing services to the MN while registered. When the MN sends IP packets, the FA may serve as a default router. While the MN is away from home, the HA uses proxy Neighbor Discovery [6] to intercept on the home link any packet addressed to the MN's HoA. The HA uses the Neighbor Discovery protocol to detect the presence and absence of neighboring nodes (hosts and routers) and, thus, the link connectivity of these nodes. Finally, the HA encapsulates and sends the packet through a bi-directional IP tunnel to the CoA.

III. Internet over DVB-T: The ATHENA Context

ATHENA is an EC Sixth framework project, which proposes the proper actions to be taken concerning the Digital Switchover (DSO) in UHF, (the transition form analogue television broadcasting to digital TV). These actions are of strategic importance for the European Member Countries and most candidate ones, as the DSO arises as a possible and complementary solution towards the deployment of Broadband Access Infrastructures, especially in less favoured regions. There, the digital switchover may arise as a unique opportunity to fill the gap in the deployment of networking infrastructures.

The ATHENA project presents an approach towards the solution of the digital switchover that comprises the use of the DVB stream for interconnecting next generation network (NGN) nodes, by the use of regenerative configurations. The utilisation of regenerative configurations enables for the realisation of a virtual common Ethernet backbone that can be exploited by 3G and B3G operators and broadcasters, besides enabling broadband access for all citizens. Such a configuration enables for multi-service capability, as the regenerative DVB-T creates a single access network physical infrastructure, shared by multiple services (i.e. TV programmes, interactive multimedia services, and most of all Internet applications, etc.).

The objective of this project is the validation of a broadband access for all citizens infrastructure based on the proper adoption of digital switchover. Its goal is to explore and validate, in a city, the deployment/realisation of the digital switchover issue through the design, implementation and evaluation of an infrastructure, which uses a regenerative DVB-T stream for the interconnection of distribution nodes, enabling access at the same time to IP services and digital TV programs (see Figure 1).

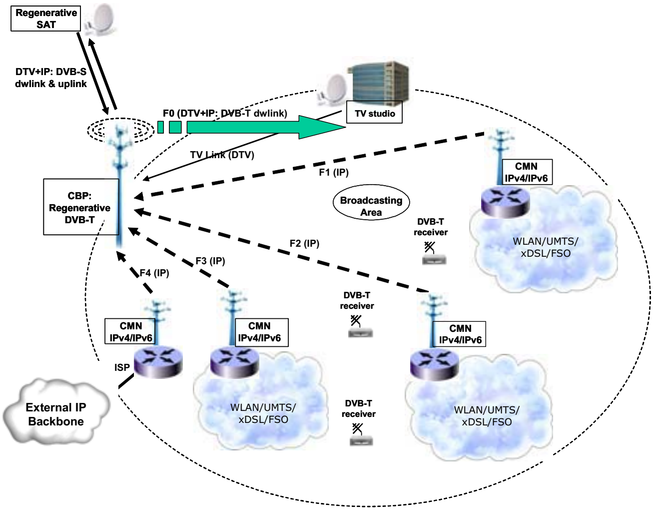

Figure 1: The Overall ATHENA IP/DVB-T Networking Context

In such configuration, all kind of citizens/providers are co-equal users of the same infrastructure via which they access (or provide) IP services. Such implementation can be used and exploited as common infrastructure by 3G and B3G operators and broadcasters having independent business plans and different users/clients.

The existence of such a neutral regenerative infrastructure (DVB-T) in a city, provides not only a bouquet of television programs, but also (and most predominant) creates a powerful broadband IP backbone (the 60 available analogue UHF/VHF channels may be seen as a virtual medium that provides an aggregate bit-rate of about 1.8Gbps). Such an approach is a possible compromise between TV broadcasters (who want the entire UHF band) and 3G operators (who claim part of this bandwidth for exclusive use).

In this approach, the DVB-T stream is used in a backbone topology and thus creates a flexible and powerful IP broadband infrastructure, thus permitting broadband access and interconnection of all local networks. The Broadcasting Area is provided with regenerative DVB-T stream by the Central Broadcasting Point (CBP). Cell Main Nodes (CMNs) enable a number of simple users (geographically neighbouring the CMN) to access IP services hosted by the network. Each CMN constitutes the 'physical interface' to the common Ethernet backbone of users/citizens of a local network (i.e. IEEE 802.11x), customers of a mobile network operator making use of 3G and B3G technology (i.e. UMTS), individual users and service providers. The return channel from the CMNs to the Regenerative DVB-T is provided through a point-to-point unidirectional radio line.

IV. ACHIEVING SEAMLESS IP MOBILITY IN DVB-T ENVIRONMENT

A. *Mobility Issues in ATHENA Context*

In ATHENA's proposed context of a multi-capable DVB-T environment, the mobility issues arising at an IP level and provoking a layer-3 handover (switching of IP addresses) are of two types:

1) Horizontal handover between CMNs with WLAN technology: A case of mobility is performed when a mobile user is switching from a WLAN to another, inside the Broadcasting Area. The case when the mobile device moves from an access point to another but keeps its IP address can be seen as WLAN mobility through switched networks. It essentially happens within a CMN coverage area. This case is undertaken by WLAN technology very efficiently and doesn't depend at all on the environment. On the contrary, when the mobile terminal switches from one CMN coverage area to another and performs a layer-3 handover, its IP address changes, and this represents WLAN mobility through routed networks (see Figure 2). In order to achieve seamless mobility in such scenario, known approaches are not sufficient. Hence, a novel mechanism is proposed, based on related works at the IP layer. The IP routing module of the CMN the mobile terminal has just joined will permit packets destined to the terminal's former address to pass thanks to a specific binding procedure.

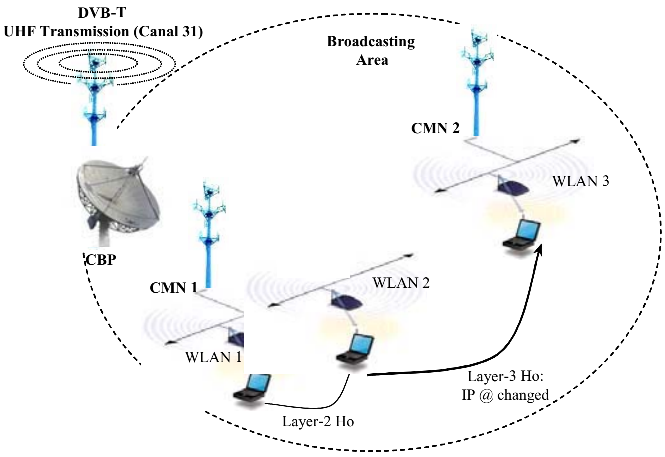

Figure 2: Mobile User performing Handovers between CMNs with WLAN Technology

2) Vertical handover between CMNs from a WLAN to a UMTS access network: A mobile terminal equipped with two interfaces, a UMTS one and a WLAN one, can perform a vertical handover, switching from one technology to another.

A roaming mobility aspect is then addressed.

As the mobile user moves across networks, the Mobile Terminal Device's (MTD) IP address may change. The mobile user, equipped with a WLAN network interface, initially moves within the Metropolitan CMN 1 accessing IP multimedia services, via the WLAN interface with address IP_0, while the appropriate reply signals are forwarded to him via the regenerative DVB-T stream. As this user moves out of the WLAN range, his MTD switches to the UMTS interface and assumes the – dynamically assigned by the UMTS (or GPRS) provider – address IP_1. Next, he may move into the range of a second WLAN CMN (CMN2) or into an area served by another UMTS provider, assuming the address IP_2. This scenario is depicted Figure 3.

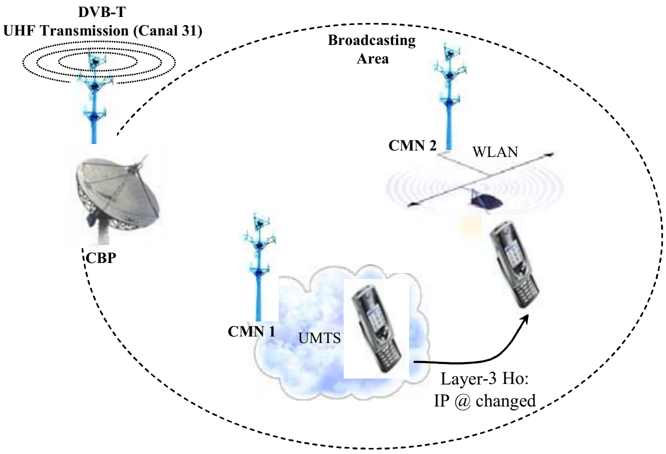

Figure 3: Mobile User performing UMTS/WLAN Vertical Handovers between CMNs

B. IP User Mobility Solution in DVB-T Environment

In order to support the mobility aspects described above in the context of DVB-T networks, an IP layer solution has been taken into consideration.

1) Mechanism Description: The proposed solution is based on Mobile IPv6 approach. As explained section II.B, Mobile IP facilitates node movement by permitting a Mobile Node to communicate with other (stationary or mobile) nodes, after changing its point of attachment from one IP subnet to another, yet without changing the MN's address. A MN is always addressable by its HoA and receives a CoA each time it visits a different network. A HA in the Home Network of the MN is responsible for performing the appropriate re-routing process, according to its Binding Cache.

Herein, we have a Broadcasting architecture; therefore all the CMNs receive all the flows (TV+IP) transmitted by the Regenerative DVB-T CBP. After the de-multiplexing and de-encapsulation process of the IP over DVB-T streams, the routing module of each CMN decides either to redirect the packets to the terminals behind it or to destroy them according to their IP addresses.

The proposed mechanism for achieving seamless layer-3 handovers in a DVB-T environment consists of the following steps, depicted Figure 4:

1. First, the MN has a HoA and receives a CoA when accessing a new subnet, covered by a new CMN. It moves from WLAN 1 to WLAN 2 and acquires its new IPv6 address from the adjacent Designed Router of CMN2.
2. At that point, the MN will inform its Designed Router (the routing module of the adjacent CMN) that it has joined its subnet and that a binding must be established between its home address and its care-of-address.
3. A Binding Update message is sent to the Designed Router (DR) and the DR replies with a Binding Acknowledgement, the same it is done in Mobile IP. The adjacent DR is considered as a pseudo Home Agent.
4. The DR establishes a Binding Cache and since it receives all the IP traffic, it can retransmit the packets destined to this entry in the Binding Cache to the respective care-of-address, instead of dropping them.
5. Timers should be set and signalling messages between the DR and the mobile terminals that correspond to an entry in the Binding Cache need to be addressed. For example, every 2 seconds, a discovery message from the DR is sent to the care-of-addresses of the MNs present in the binding cache. If there is no response from the MNs, it means that the MN is not in the subnet anymore and consequently, the corresponding entry in the BC is deleted and the packets are not re-transmitted.
6. If mapping of PIDs and IP addresses is performed at the Regenerative DVB-T (CBP) side, control data is sent by the CMN in order to set dynamically a new appropriate IP address/PID mapping entry.

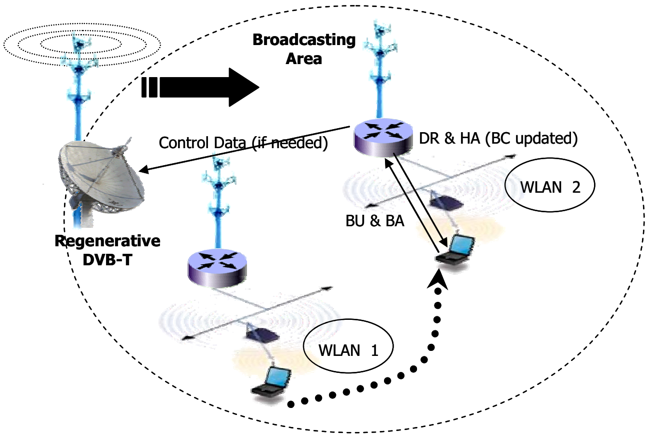

Figure 4: IP Mobility Mechanism in DVB-T Context

2) Multicast Support: Multicast is essential in such a multimedia-based environment since most of the relevant applications use this transmission technique. In order to be coherent to the former status of DVB environments, in which by definition broadcast is the leading technology, there is a need to deploy the corresponding delivery technique, by means of multicast.

In such environment, all the CMNs will receive all the multicast flows delivered in the network. No multicast routing process, as in native IP networks, needs to be present. Each CMN has to decide either to pass the multicast packets to the adjacent access network behind it or to block them, depending on the requests of the users. Thanks to IGMP or MLD messages, the users inform their corresponding CMN of their will to register to the desired multicast stream.

Concerning mobile nodes, a Mobile IP Remote Subscription process is thus established for multicast receivers, as depicted Figure 5. In order to receive packets sent to a given multicast group, a mobile receiver needs to first join that multicast group. With the remote subscription approach, the mobile receiver joins the multicast group via a local multicast router on the foreign network. To join a multicast group, an MN sends its membership report message to the local multicast router located on the visited network. The local multicast router intercepts this membership report message and joins the requested multicast group. Following this approach, the MN uses its CoA as the IP source address when sending its membership report message to the multicast router MR1. After handover to the foreign network 2, MN again sends a new membership report message to MR2 by using its new CoA. While the MR2 constructs a new multicast branch for the MN, the MR1 may stop re-transmitting the multicast flows to the access network behind it if it has no other receivers.

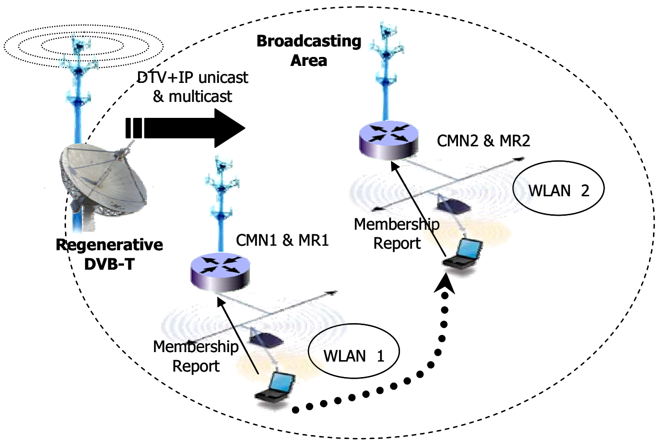

Figure 5: Mobile Multicast Support in DVB-T Context

V. Development and Demonstrations

Within the framework of the IST project ATHENA, the development of such network architecture, as well as the integration of proper modules, has been performed. One demonstrator has been set-up at the premises of the Centre of Technological Research of Crete (CTRC) in Heraklion City, Crete, Greece.

The networking configuration has been established in IPv4 and in IPv6, through the addressing and routing processes, as well as end-user autoconfiguration mechanisms. An IPv6-to-MPEG2 encapsulator has been implemented at the Regenerative DVB-T side and IP routing modules at the Cell Main Nodes. Figure 6 shows the IPv6 networking configuration of the ATHENA demonstrator.

The modules of the IP mobility solution for IP mobile users in an hybrid IP/DVB-T environment have been developed for IPv6 only. The use of IPv6 addresses and Router Advertisements for the end-users permits a successful integration of the modules inside the overall platform. The work being held so far includes the development of most of the points of the mechanism, all those that are located at CMN level. As well, the multicast support is efficient since no cooperation with the Regenerative DVB-T CBP is needed for this point.

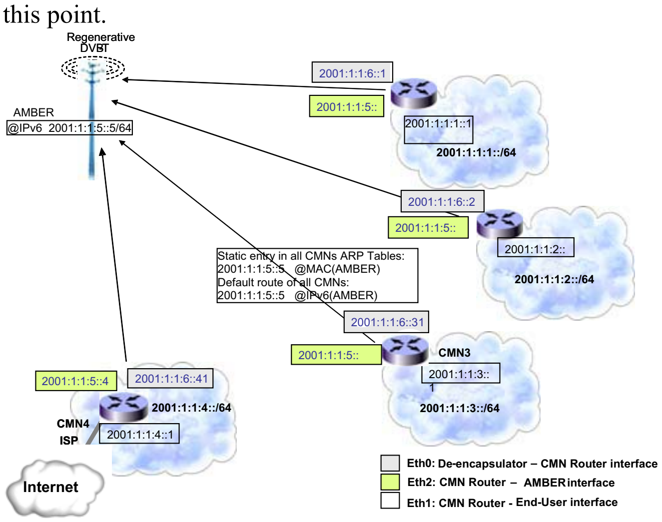

Figure 6: ATHENA Demonstrator Network Configuration

VI. Conclusion

In this paper, we presented an architecture that takes into consideration the use of regenerative DVB-T streams for the transport of both TV programs and IP flows at the same time and through the same frequency channel. As well, we proposed an efficient solution for IP users to perform seamless handovers in such a context, as well as a support for mobile multicast applications.

Validation of such a broadband access for all citizens infrastructure, based on the proper adoption of digital switchover, has been realised in a real condition trial in a medium-sized city (Heraklion city, Crete, Greece), within the framework of IST project ATHENA.

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