Heterogeneous Networking in the Home Environment

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Abstract

The management and control at multiple protocol layers of a heterogeneous networking structure, to support multimedia applications in the home environment, is considered. The paper examines possible scenarios, and corresponding architectural solutions, also in the light of existing wireless and sensor networks technologies.

Introduction

The support of multimedia applications with seamless connectivity in the home and beyond is a challenge for the integration of various wireless communications platforms (Wireless Body, Personal and Local Area Networks – WBAN, WPAN, WLAN – plus wireless sensor networks), both with one another and with external access networks (wireless and wired). In this context, it is important to identify the various components, and to characterize them in terms of their functionalities for Quality of Service (QoS) and mobility. Basically, the need arises of a flexible and secure ad hoc network architecture, where devices should be able to operate both as terminals and network nodes, in multi-hop and meshed fashion, and allow dynamic reconfiguration. In this context, the computational, energy and transmission resources should be managed and controlled, in order to provide adequate support for multimedia content distribution platforms.

The management and control of the overall networking environment can be viewed under two complementary and related perspectives. As far as multimedia content distribution is concerned, a higher-level content and service management is required, which must ensure seamless context-aware distributive and interactive services. This abstraction level has to deal with objects accessed by means of proper middleware, ensuring object publication and discovery, as well as security and authentication. The management components at this layer of the management plane should act on a relatively longer time scale (with respect to lower-level networking components). At the access and transport network level, management and control actions will happen on a shorter time scale, and should be concerned with QoS preservation and mapping across multiple networking domains. It is foreseeable that QoS mapping will take place at domain boundaries, within dedicated gateways or edge routers, in an environment characterized by the presence of both Best Effort and QoS IP networking paradigms.

In relation with the goals of the recently launched European Network of Excellence (NoE) INTERMEDIA [1], the paper examines the state of the art in the above-mentioned wireless networking technologies, sketches a definition of the heterogeneous network architecture and of its main components and functionalities, and gives a hint on possible management and control strategies to support dynamic content distribution.

The INTERMEDIA vision in Home Networking

a. The user-centric approach

The economic driving force behind new communication paradigms has given more emphasis to the concepts of integration and convergence. The core element in this process is represented by networking, which must evolve toward intelligent, autonomic and self-configuring structures, capable of offering flexible and efficient support to all evolving user needs [2].

So far, the convergence effort has been pursued in two distinct areas, involving multimedia communications and mobility. The first case includes *home-centric* systems: indeed, a large and differentiated number of multimedia devices are commonly found in the homes, both for reproduction and recording of contents [3]. Such systems are often independent, and they may communicate through dedicated cabling or exchange of storage supports. Convergence in these systems represents the key toward new communication capabilities, connected with seamless content sharing across multiple devices. Among other examples, we may mention the possibility of watching a movie, coming from the PC hard disk or from a satellite broadcasting, indifferently on the PC or on any TV screen in the home, or of sharing images between a digital camera and any other supporting device (PC, printer, DVD player), without having to set up dedicated cabling and software; as regards the office, the seamless sharing of an agenda among a multiplicity of devices (fixed, portable and handheld PC, mobile and fixed phone, etc.).

On the other hand, in such a scenario little attention is given to the user's mobility, which is often confined to within the home. This aspect is taken into account in the concept of *device-centric* convergence, aiming at providing services no longer on a large number of devices within a restricted area, but rather on a portable and flexible device that the user can carry; the device should be capable of interacting with diverse networks, in order to access the desired contents. Modern cellular phones and palm PCs represent an example of this trend, though with the presence of factors intrinsic in their portable nature (constraints on volume and weight, power consumption, costs), which severely limit the reproduction power and quality of the interfaces that can be made available to the users.

The vision at the basis of the INTERMEDIA NoE represents a further evolution in these concepts, aiming at the convergence of multimedia content sharing and mobility in a *user-centric* paradigm. The idea at the basis of this approach consists in viewing the user as the central element in the convergence process. The user becomes part of the networked system, and is enabled to exploit all capabilities offered by portable devices in terms of mobility, while at the same time adopting the interfaces that become available in the ambient, to access, reproduce and share multimedia contents. In the technological scenario identified in the project, the user exploits "wearable" devices and interfaces (e.g., palm computers, cellular phones, MP3 readers, some of which may be integrated in the suits), which communicate among them in a WBAN and with the surrounding environment, by using any available technology (cellular networks, ad hoc networks, etc.). Multimedia convergence allows the user to adopt the different communication interfaces as they become available, transparently and automatically, owing to the presence of the devices being worn. Just to make an example, imagine a person listening to music or broadcast news at home, who is about to go out to reach the office. Without any interruption, the audio content the person was listening to continues to be downloaded by the cellular phone and, later on, by the radio in the car, which are aware of the content being played and of its network location (e.g., whether it is being downloaded from the network, from some storage device at home, or from some wearable one, where it was temporarily stored); listening can be continued seamlessly from the office PC. The mobile devices being worn or carried by the user allow the transparent configuration "on the fly" of other multimedia equipment which appears in the user's range, in a cross-ambient fashion. In such a scenario, the user only needs to activate the service, leaving then the task of mobility and multimedia delivery handling to the network, on the best interface that becomes available in the surrounding ambient.

The *user-centric* vision poses a number of technological challenges mainly regarding the aspects of *Dynamic Mobile Networking*, *Multimedia Content Adaptation and Sharing*, and *Personalized Interfaces*. The use of multiple devices, fixed and portable, requires the definition of common interfaces and formats, as well as the adaptation of multimedia contents to the different capabilities of the reproduction device and of the network being used. From another viewpoint, sharing or accessing sensitive contents through multiple wireless network domains may represent a non merely technical problem, as is the case with strictly personal or copyright-protected material: in both cases, adequate privacy and protection are required. As regards the aspects related to networking, problem areas embrace the middleware layers that allow applications to seamlessly follow the user moving across networks, the presence of a common control plane over heterogeneous networks, offering a homogeneous service to the applications (in terms of QoS, handoff between access points, security), and the adaptation to different MAC (Medium Access Control) layers [4,5].

b. Integrating Wide Area, LAN, PAN, BAN and sensor networks

As previously noted, the vision of Intermedia is user-centric: no matter which devices are actually used and their physical position, the user can access the multimedia services offered by the surrounding environment (for instance his home, car, office) through a personalized interface.

We now take a closer look at the design of the communication infrastructure that enables such a vision. In our opinion, this infrastructure will include three main components:

a) a network that enables wide bandwidth communications among devices, thus allowing the use of powerful equipment deployed in the environment, which offers multimedia services;

b) a low-energy, low-bandwidth sensor network, which provides feedback from the environment and feedback implicitly generated by the user;

c) a gateway towards external networks, such as Personal Communication Networks (including mobile cellular networks), the Internet, or dedicated satellite networks, which may provide updates and multimedia contents not locally available.

We propose a possible scenario first, and then we discuss the available solutions for the implementation of the various components in order to realize the proposed scenario.

It is 8 a.m. in the morning and Nick is still sleepy in his bed when his answering machine receives a video message: it is his boss who is reminding the meeting in the late morning and passing a video document to be inspected before the meeting. Few minutes later, Nick's girlfriend Lisa sends a vocal message to invite herself for breakfast and to invite Nick to an excursion on the hills in the afternoon; she also passes a few pictures and a tentative program for the excursion. These messages are interpreted by the answering machine: it asks the clock to wake up Nick immediately, it checks if there are still croissants and milk in the fridge for Lisa, and it warms up the oven; then it checks if Nick is already awake (if not it asks the clock to insist…). Once Nick is ready, the answering machine shows him the boss's message. It also passes the video document to Nick's jacket, so that it can be displayed in the cab during the trip to the meeting place and, of course, it calls for a cab!

Then, the answering machine plays his girlfriend message for Nick, while displaying the pictures. The jacket collects the pictures and the program of the journey and uploads a few country music pieces; it knows that Nicks loves country music while walking in the countryside. The jacket, which does not trust the weather forecast too much, also checks for the weather outside: there is a light rain, so it suggests Nick to take the umbrella. Note that the jacket could also collect information relevant Nick's body reactions to the music he is listening (hart-beats, blood pressure, etc.), for example to lower the tone or to change music.

In this scenario we first notice three kinds of communications:

1- Communications with external networks: two incoming calls (one from the boss and one from Lisa) and the outgoing call for a cab. In some cases these communications carry along multimedia documents (the program with the pictures, the video document).

2- Communications between different devices: i) the answering machine with the jacket, the clock, the fridge, and the display for the video messages; ii) the jacket with the stereo.

3- Communications of different devices with a set of sensors for the acquisition of environmental and body parameters: is Nick awake? Is it raining outside? Are there any milk and croissants in the fridge? Which is his pressure, etc.?

We observe that these kinds of communications are rather different from an architectural point of view. In particular, from the point of view of INTERMEDIA, communications in point 1 involve a gateway between the local networks and the external networks.

Communications in point 2 involve heterogeneous devices, particularly in terms of energy constraints, but also in terms of memory, processing, and bandwidth. For instance, the fridge and the oven are permanently connected to electrical wall sockets, so that they may embed powerful devices in terms of processing, memory and radio features, while other devices, such as the jacket or the clock, are battery-powered. Consequently the communication protocols, together with the processing and memory features, should be designed accordingly to a constrained use of energy.

We also note that devices exchange different kind of data. In some cases, they exchange multimedia documents (video, travel plans with pictures), while in other cases they request for alarms (to the clock, for example). These observations suggest that the network that supports these communications may not be unique; in fact, we might have two or more overlapped networks with different features in terms of bandwidth, QoS, and energy consumption. These networks may intersect at some gateway, typically nodes with no power constraints, such as the answering machine or the fridge.

Still in point 2, we observe that some of the nodes, such as the jacket, are mobile (although the mobility is limited), while others are static (e.g., the fridge); hence, the communication infrastructure should take into account this aspect, as well.

The communications in point 3 are queries directed to sensors deployed in the environment. Typically, these sensors are battery-powered and they are several orders of magnitude less powerful than devices such as the jacket. This happens because it is feasible to recharge the jacket at the end of the day, but it may result infeasible at all to recharge tens of sensors deployed in different places.

For these reasons, we also expect that the sensors do not provide connectivity to other devices; rather, the sensors form a network by themselves, and a set of *sink* nodes act as gateways between the sensor network and the other networks. Note also that in some cases these queries are directed to one sensor, while in other cases they are executed by combining a set of sensors' readings. For instance, determining weather or not Nick is awake may need readings from pressure, light and position transducers; while determining if it is raining may require readings from a set of humidity transducers. This means that the sensor network will also perform in-network data aggregation and processing.

As a further note, we observe that most likely the sensors will be static; however, the sinks might be mobile (this is the case of the jacket, for instance). This has implications at different layers of the protocol stack of the sensor network.

The overall logical architecture is sketched in Fig. 1.

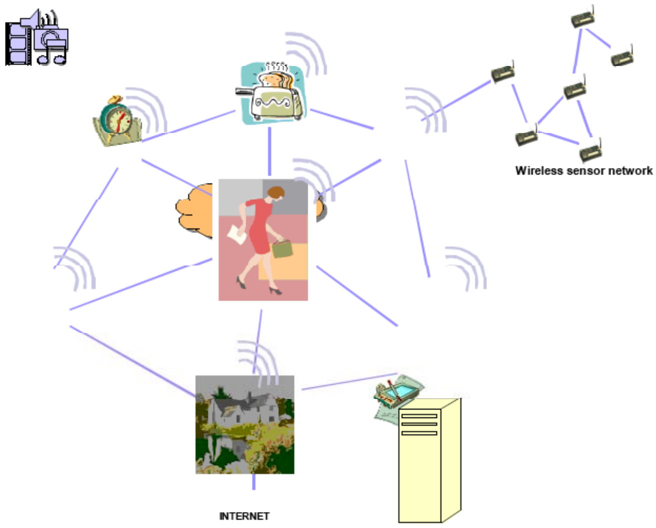

Fig. 1. A sketch of the logical architecture.

Several technologies can be considered in order to support the above-described scenario; some of them are still in their youth, others are already mature. We consider standards such as IEEE 802.16 (WiMax, as one of the possible alternatives to connect to the external world), IEEE 802.11 (Wi-Fi), IEEE 802.15.1 (Bluetooth), and IEEE 802.15.4 (Zigbee) and de-facto standards (such as TinyOS) as a good starting point for the design of this architecture. In particular, Wi-Fi and Bluetooth could result useful for transmission of multimedia contents. Wi-Fi may be used to support mobility, while TinyOS or Zigbee might be considered for the sensor network.

However, some issues are not completely solved by these standards. Management of mobility within Wi-Fi networks is defined by the standards and is found in commercial equipment, but not so in Bluetooth equipment. Transmission of multimedia content when the data flow is near to the capacity limits of the wireless link may be problematic and calls for appropriate coding solutions.

Zigbee may result a good solution for the sensor network; however, the standardization (IEEE 802.15.4) is limited to the MAC layer, while TinyOS provides a scheduling and device management support of the sensors. For the upper layers there are different suites of protocols/middlewares (in particular under TinyOS, for instance TinyDB, Cougar, and MaD-WiSe) with different aspects in terms of performance, features, cost and accessibility, to be checked against the INTERMEDIA requirements.

Finally, as a further issue, we mention the cohabitation among the various networks, which may interfere with each other.

A brief overview of wireless network technologies

The presence of a number of standards in the area of short-range wireless networks (WLAN/PAN/BAN) reflects the various application fields and the technological evolution that have allowed the proposition of the new generation of these networking paradigms also in the fields of multimedia and home networking [6].

The most widespread standard is certainly IEEE 802.11 [7], which well represents the evolution of this type of networks, with its numerous amendments in the course of the last decade. The first version appears in 1997, in competition with the HiperLAN ETSI standard [9]; however, since the beginning the market trend favors the IEEE solution and, despite better performance, the ETSI standard stops at the second version (HiperLAN/2), not raising consensus on the part of manufacturers. The first version of IEEE 802.11 was limited to 1-2 Mbit/s, but the large diffusion encouraged a large number of amendments [8], aimed at overcoming numerous initial drawbacks: transmission speed has been increased by both versions b (11 Mbits/s) and a/g (54 Mbits/s); a new series of MAC protocol features that support QoS in a distributed environment have been introduced by 802.11e; network security has been enhanced, both for data and management traffic, by version i/w; more attention has been given to handoff procedures, especially in relation to QoS handling (802.11r); the concept of multi-hop network has been considered in version s, and more solid basis for internetworking with other technologies have been posed by 802.11u; at the physical layer, amendments have been dedicated to coping with the legislative constraints in different countries as regards spectrum allocation (802.11h/y). Current implementations allow transmission speeds of 54 Mbits/s over distances in the order of 100 m in open space, and are already sufficient to support a good deal of applications in the home. Future perspectives aim at speeds of 200-540 Mbits/s, as foreseen in the current draft 802.11n, by leveraging on the technological heritage of the by now abandoned HiperLAN/2.

The PAN segment is also dominated by IEEE standards. Different application areas are considered with separate proposals in the IEEE 802.15 family. The most well-known protocol in this context is 802.15.1 [10], compatible with the Bluetooth consortium specifications [11,12]: a network architecture that, in practice, finds most applications in point-to-point communications aimed at eliminating cabling in short-range communications between devices. It is worth noting that a possible antagonist here might have been the HomeRF proposal [13], explicitly aimed at the home environment (even in competition with 802.11), which, however, has been overwhelmed by the growing market interest in the IEEE standards, causing the end of the HomeRF project in 2003.

The other parts of IEEE 802.15 define protocols for specifically aimed PANs: High-rate PAN (802.15.3) and Low-rate PAN (802.15.4). The objective of High-rate PANs [14,15] is the support of short-range multimedia applications. Indeed, Bluetooth transmission speed of 1 Mbit/s is sufficient for voice/audio and non-real-time data, but would be largely inadequate in a full multimedia environment and for the elimination of high-speed cabling (VGA-monitors, Firewire, USB). The technology at the basis of 802.15.3 is UWB (Ultra Wide Band) at the physical layer (IEEE 802.15.3a [14]), in substitution of the Frequency Hopping (FH) of 802.15.1. UWB [16] can spread the transmitted signal power over a much wider portion of the spectrum (the foreseen bandwidth is between 3.1 and 10.6 GHz), thus generating very low interference to other applications in the same frequency band. Two different physical layer options have been considered: Direct Sequence UWB (DS-UWB), supported by UWB Forum and aiming at transmission speeds up to 1.3 Gbit/s; Multi-Band UWB (MB-UWB), supported by WiMedia Alliance, limiting to 480 Mbit/s – already sufficient to replace the majority of current cabled technologies, also in multimedia communications. IEEE 802.15.3 is in competition with other proposals arising from manufacturers' consortia in this area; among them, we can mention Wireless-USB and Wireless-1394. Unfortunately, ideological divisions among different associations, market uncertainty and diverse international regulations have caused a substantial stop in the project development at the beginning of 2006, by delaying choices on the technology to a moment of better clarification of the scenario. A possible alternative to UWB is represented by the use of millimeter waves (802.15.3c), operating in the 57-64 GHz range, with transmission speed in the order of 2 Gbits/s.

A very different approach has been taken in the Low-rate PAN field, as the latter is addressed towards applications in the sensor area, where the energy aspect has paramount importance: low data rates and limited transmission range are adopted to maximize battery duration and, accordingly, the life of the sensor itself. The IEEE 802.15.4 standard [17] defines both the physical layer (PHY) and the medium access control sub-layer (MAC) for ad hoc, multi-hop and self-configuring networks. The IEEE 802.15.4 defines two PHY layers according to the operating frequency, both based on Direct-sequence spread-spectrum (DSSS); the 2.4 GHz and 868/915 MHz frequency bands can be used. Data rates vary in the range of 20 kbit/s up to 250 kbit/s, depending upon the operating frequency band. The unlicensed industrial, scientific and medical (ISM) radio band at 2.4 GHz offers the maximum rate (250 kbit/s). The MAC sub-layer employs the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism for channel access, as the 802.11 standard, but it does not include the request-to-send (RTS) and clear-to-send (CTS) mechanism. Three different data transfer modes are provided: *Direct data transmission*, *Indirect data transmission* and *Guaranteed time slot* (GTS); Unslotted CSMA/CA or slotted CSMA/CA is used in the former two cases, while no CSMA/CA is required in the latter. There are two different types of network topologies implemented in 802.15.4: a one-hop star, or a multi-hop peer-to-peer topology. The 802.15.4 allows the optional use of a superframe structure, bounded by network beacons and divided into 16 equally sized slots. In such case a coordinator must be present to define the format of the superframe. The MAC design has been intentionally kept minimalist in order to obtain a simple and cheap hardware implementation of devices; more network stack elements above 802.15.4 are needed to create and manage a real network architecture. There exist two different proposal: *Zigbee* [18] and *6lowpan* [19,20]. The former derives from the homonymous alliance and it defines a real ad hoc network level for this kind of applications (network topologies, configuration, identification of active nodes), on top of which specific applications for this type of devices can run; the latter is an IETF draft, aiming at building an adaptation layer between 802.15.4 and IPv6 (version 4 is not envisaged), by delegating all the security and configuration issues to the well-known protocols in the IETF TCP/IP framework.

It appears quite clearly as the different wireless technologies available nowadays are able to cover a wide range of applications, which often results very heterogeneous. At present, no single standard can prevail over the others, and this is unlikely to ever happen, due to extremely different requirements of the several application scenarios. The most sensible view is therefore the coexistence of a variety of different networks, scarcely interfering at the physical layer, this being an issue faced in the different standards (e.g., 802.15.2). However, this raises a series of non-trivial issues in a user-centric environment, where very heterogeneous networks must interact: BAN/PAN/WLAN. In such a scenario, diverse networks are available, and the same devices could use more than one of them, to fit their performance to the surrounding ambient: thus, user mobility requires suitable handoff procedures (both "horizontal", between different working areas of the same network, and "vertical", between networks of different kind). The latter may be relatively frequent, due to the typical limited extension of such kind of networks, ranging from the few cm of BANs to several hundreds of meters in WLANs. Handoff is a complex issue even for a specific technology as, together with the main aspects related to some kind of change in the physical layer (frequency, code, modulation, rate, transmission profile, etc.), it has side effects on other aspects related, for example, to security and quality of service of the traffic; it is quite intuitive that the overall problem results even more critical when the handoff occurs between technologies that use different mechanisms. To make an example, let us just imagine the transition from a 802.11 network, where traffic is encrypted by WEP, towards a Bluetooth *piconet*, where the authentication and encryption mechanisms, as well as the key sizes to be used, are very different. Among the factors that help in making this kind of operation technically complex, we can recall the presence of multimedia traffic, often real-time in nature, which poses strict time bounds, the presence of very simple devices, with limited computational capabilities, the high error rate in radio transmissions, which requires suitable detection and recovery mechanisms, and the intrinsic "open" and insecure nature of air, which needs strong security algorithms.

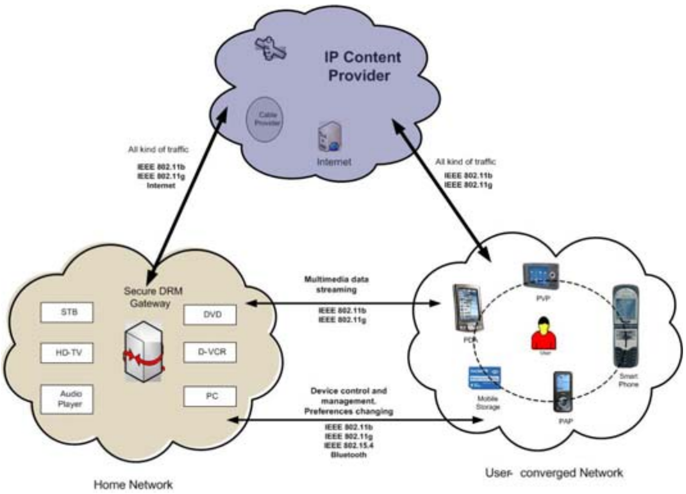

Fig. 2. Possible communications scenario.

Fig. 2 illustrates the architecture of a possible INTERMEDIA communications scenario. More specifically, in an indoor home environment, the user can communicate with various multimedia and sensor devices as well as the home server through the wireless 802.11b, 802.11g and 802.15.4 technologies, supporting multimedia and sensor content applications. On the other hand, in an outdoor environment, the user has the ability to communicate with the home server through a wireless LAN or wireless MAN (WMAN) network or even via an Internet connection through a WMAN providing Internet access.

As holds in most cases of multimedia and sensor applications or possible communication scenarios, the user perceptive quality defines tight QoS requirements that the heterogeneous network should support. Hence, the QoS, regarding the MAC sub-layer, should be evaluated, by modifying various MAC parameters for different communication scenarios with respect to power consumption. In addition, useful outcomes can be provided in regard to QoS and power consumption trade-offs.

Security and Digital Rights Management

One key issue in home networking is related to the Intellectual Property of contents being distributed. As a matter of fact, multimedia distribution across several kinds of devices and networks, which can communicate among them, facilitates the convenient distribution of digital artifacts like audio, video, etc., among users, most of the times illegally and without the necessary licensing. Digital Rights Management (DRM) mechanisms consist of various technologies that have been developed and deployed by content providers, creators, distributors, in order to protect their digital media from usages that may be illegal, unauthorized and without the appropriate rights of their products. At the same time, DRM facilitates the use of possibly unsafe media like the Internet for delivery of these products with less hesitation and anxiety about non-legitimate usage of their content. This problem is even more stressed in PANs, where content distribution among users and their usage generally takes place in an autonomous and uncontrollable form, due to the likely absence of a public connection. Various methods and numerous DRM systems have been developed for the protection of Intellectual Property, (see [21] for a quick overview). What characterizes most of them is the lack of interoperability, i.e., different content providers use different non-standardized, non-interoperable DRM systems, which may create great problems in contents usage by legitimate users, thus breaking the user-centric concept.

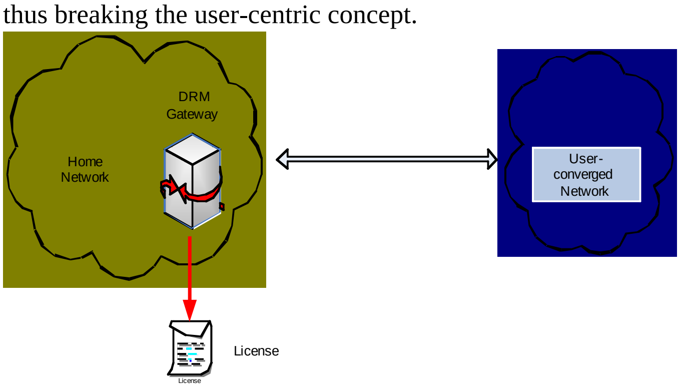

Fig. 3. a) DRM gateway shall generate licenses for contents usage according to Home Network's (HN's) initiative.

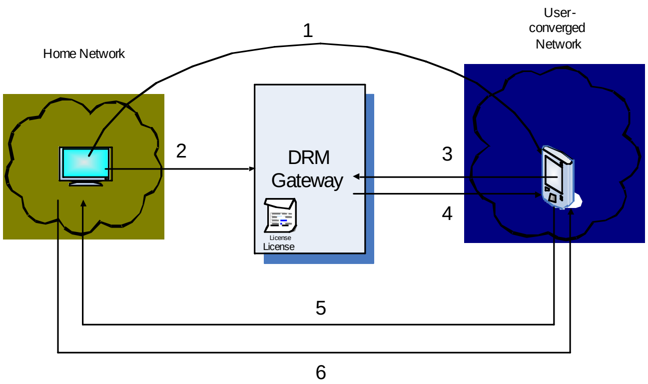

Fig. 3. b) A typical scenario is as follows, (1) HN initiates a transaction towards a terminal that belongs to the user-converged network, while in (2) HN requests the generation of an appropriate license by the DRM gateway. In (3), (4), the license is transferred to the terminal and finally in (5), (6) the content is transmitted to the terminal, possibly transcoded. In that case, the terminal has the full responsibility for content's usage and enforcement of its license

Within this field, much effort should be devoted to develop and deploy technologies that shall permit, transparently to the end-user, the continuity of various multimedia sessions over heterogeneous networked environments; on the other hand, they should guarantee that the digital rights of multimedia contents are kept secure and under the terms specified by their licenses. A DRM system must be developed, by keeping in mind issues like: interoperability and heterogeneity of environments; weaknesses and constraints of participating entities; various security challenges that may arise; scalability and easiness of adaptation under changing requirements; QoS provision, without compromising the architecture's primary functionality; and real-time constraints for real-time (live) contents. This can be achieved, for example, by using a DRM gateway for generation of licenses to be transferred to each device before the multimedia content; the generated licenses could be compatible with MPEG-21 standard's requirements, since that framework works towards the solution of interoperability problems [22]. A possible configuration is depicted in Fig. 3.

Our vision here is to manage the implementation of a real-time DRM for live (real-time) transmitted digital contents. In order to accomplish this task, we start with the development of a "near"-real-time DRM system for stored contents between HN and user-converged network; then, we could refine our system, by allowing the provision of real-time DRM for stored contents, leading us, eventually, to a DRM system that shall provide real-time DRM for real-time (live) contents.

QoS management across multiple domains

Multimedia distribution in a heterogeneous home environment requires a high degree of cooperation between a common higher layer involved in content delivery and specific lower layers dealing with QoS in each management domain. At the higher layer, the service definition and delivery must be tightly coupled with multimedia content adaptation and multimedia content sharing functionalities, in order to meet the intrinsic limitation imposed by each network traversed (mainly in terms of throughput, error rates and delay). According to the service profiles, the content coding, storage, delivery and reproduction requirements, target values for the parameters of the underlying physical networks are then set within each domain. At the same time, content adaptation and service delivery may be influenced by feedback from the lower physical layer of the single networks, within the limits imposed by the service requirements.

In an effort to minimize network traffic and ensure a better QoS, a Content Delivery Network infrastructure can be set, where part of the central server's content will be mirrored to distributed servers near the end users. Each distributed server will hold only part of the available content so as to avoid unnecessary duplication. The selection of the content to be delivered through each of these servers will be made by the system in accordance with the profile, recent preferences and schedule of the users that reside near the end servers and use the offered service.

Consider, for instance, the case of a mobile user, who roams to a network with different characteristics. This fact is detected by the lower-level network management and notified to the upper level content and service management. In turn, the content and service management can react by operating a content adaptation and/or a reconfiguration of the service distribution chain. Reconfiguration in this setting may mean requesting the lower-level network management for changes in the QoS or in the bandwidth reservation, but also (at the upper level) selecting different servers/proxies involved in the content distribution and/or changing their assigned load.

The key for the performance and efficiency of the network lies in the interaction between the two levels. In fact, the upper level is aware of the content and of the user profiles and needs, while the lower level is aware of the specific characteristics and current situation of the underlying networks.

It should be observed that the feedback generated by the underlying networks to the content and service management level should be given through well-defined interfaces, to ensure independence between the two levels; moreover it should be dynamic, to meet runtime changes in network conditions.

A sketch of the overall protocol architecture is represented in Fig. 4.

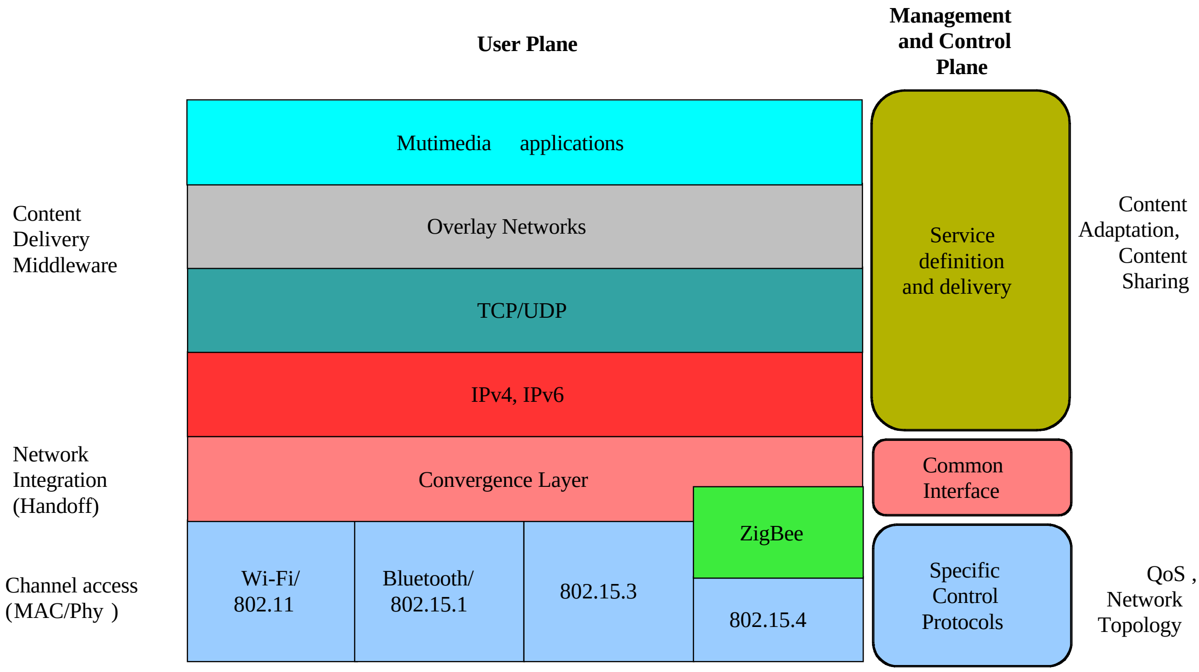

Fig. 4. Overall protocol architecture.

Conclusions

We have briefly examined some of the main aspects connected with the wireless networking support of multimedia applications within the home, in the light of the INTERMEDIA project framework. The user-centric nature of INTERMEDIA has been highlighted, and the ensuing networking requirements have been analyzed, also in relation with the current technology trends. The future work in this area within the INTERMEDIA NoE will be aimed at the further specification of the architecture, to the choice of the best-suited technologies, and to their application in the specific environment.

Acknowledgments

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