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COMPLETING THE CONVERGENCE PUZZLE: A SURVEY AND A ROADMAP

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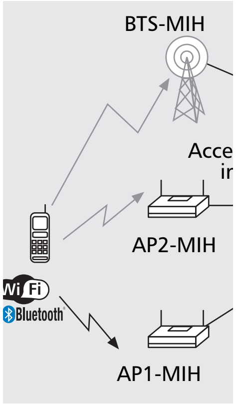

The authors survey different technologies which offer seamless handover and converged access to mobile voice, video, and data services.

ABSTRACT

Convergence has more than ever been a central issue for fixed and mobile operators throughout the world and is considered to be the next big step in the evolution of telecommunication networks. Convergence opens new market opportunities and competition among network operators and above all offers enhanced user experience. Multimode handsets and the proliferation of terminals and access technologies are generating increasing demands for solutions that enable convergence, seamless handover, and transparent service delivery across heterogeneous access networks. Different strategies are available for operators, depending on the services they intend to deliver to their customers, from basic commercial convergence limited to unified billing for Fixed/Mobile/Internet up to in-dept network convergence covering new applications and services.

This article surveys different technologies which offer seamless handover and converged access to mobile voice, video, and data services. It provides first the different network parts involved in defining the operator global convergence strategy and then surveys different technologies which achieve this step-by-step convergence. We present the main features of these technologies and discuss their limitations and potentials to enable convergence in heterogeneous networks. We also provide a personal stance as to the emergence of these technologies and our vision towards the long term converged telecommunication networks.

INTRODUCTION

The proliferation of fixed and mobile access technologies and communication devices have highly enlarged the choice for network operators and service providers to offer a wide variety of services. This context is illustrated with access networks such as the Universal Mobile Telecommunications System (UMTS), WiMAX, WiFi, digital video broadcasting (DVB), and heterogeneous mobile terminals (e.g., smartphone, PDA), supporting enhanced integration of applications. Currently, with the massive interest in the deployment of these mobile broadband wireless technologies, the integration and convergence of these networks and technologies is becoming not only possible, but also a necessity to provide several value-added services to consumers at affordable prices. In the past few months, convergence (eventually with seamless mobility) has more than ever been at the center of fixed and mobile operators' attention throughout the world. From a technical perspective, it is considered to be the next big step in the evolution of telecommunication networks. For instance, wireless technologies such as WiFi offer high data rates at low cost but do not guarantee seamless coverage, especially with high mobility. Bluetooth technology supports low data rates compared to the hotspot technologies, but saves in the power consumption required for wireless access. In contrast, cellular networks such as Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS) and UMTS provide wide area coverage and support high mobility at a higher cost (when assessing the bandwidth cost). From marketing perspectives, thanks to its technical edge, convergence allows the operator to enlarge its portfolio and attract more customers with new and aggressive offers as the same services are likely to be provided over all existing networks (fixed and mobile).

In such a diverse environment, the concept of being always connected becomes always best connected [1, 2]. This refers to being connected in the best possible way by exploiting the heterogeneity offered by the access networks in order to experience a large variety of network services, particularly in the event of user mobility (accessing services using various terminals). Moreover, end-user devices are increasingly equipped with multiple interfaces enabling access to different wireless networks subject to network availability, device characteristics, and the applications used, all of which introduce the need for network interoperability in this heterogeneous environment. Also, the tremendous growth of connected wireless devices has augmented the endless competition for scarce wireless resources and has significantly exposed the challenges for heterogeneous network resource management. It therefore consists, for the operator, of selecting the most efficient network for ongoing user sessions with regard to network cost efficiency and user experience efficiency.

In this increasingly heterogeneous networking architecture, integration and convergence can be achieved in different ways by integrating technologies at different levels and ensuring efficient roaming solutions [3]. From basic commercial convergence (unified billing for fixed/mobile/Internet) or basic service convergence (a service provider allowing service delivery across different access networks without the need to support mobility management), to network convergence (transparent service delivery when changing access, with service continuity and seamless mobility), different strategies can be adopted by operators, depending on the services they want to deliver to their customers. In this article we provide a comprehensive survey of each of these technologies highlighting their design goals, architectures, and protocols. A comparison study illustrating their differences, advantages, and limitations is also presented. We conclude by presenting our personal views on the evolution of the discussed technologies toward true and ubiquitous convergence of these heterogeneous networks (also named seamless convergence in this article).

SEAMLESS CONVERGENCE: A LONG-TERM VISION

The beyond third generation (B3G) network is a multitier hierarchical system that supports IP-based mobile multiparty multimedia services over heterogeneous wired and wireless networks. Convergence is the key word used to refer to those networks that offer unified solutions where heterogeneous components are seamlessly integrated and interoperate to provide service conformity and assurance to customers. While the research community is interested in the integration and interoperation of B3G heterogeneous networks at various scales, in this section, we focus our discussion on convergence aspects which are relevant in a service provider network.

Seamless network architectures can be roughly classified as those ensuring either the mobility of users accessing services with various terminals, or the mobility of the terminals accessing services across access networks. An example of mobility for the first class (mobility of users accessing services with various terminals) is to allow a user to transfer, when at home, part or all of a set of media in an ongoing session toward another terminal with more appropriate capabilities. Each type of convergence is coupled with the services that can be supported with different impacts on devices and network infrastructures. For instance, seamless mobility is expected for voice services, whereas some resuming or bookmarking features without seamless mobility can be satisfying for streaming services. The heterogeneity convergence of concern to the operator is illustrated hereafter through an enforcement of convergence at four network levels (the home network, access network, core network, and application server levels). The long-term convergence for an integrated operator (offering both fixed and mobile services) will be built by integrating these four convergence streams within its global strategy on network and service evolution.

HOME NETWORK CONVERGENCE

Home network convergence can be defined as the capability to break the silo approach where a terminal is dedicated to the use of a given service. Home network convergence allows the following benefits:

- The user can access different types of services from the same terminal. An example is the ability to handle a call with a handset and be able to display on this same handset content retrieved from another device located in the home network.
- A service is available on more than one handset. For instance, the video-on-demand (VoD) service is not only displayed on the user's television screen but can also be viewed on a PC or mobile handset.
- Diverse communication technologies are expected within the home network sphere. Most prominent are WiFi, power line communication (PLC), and Gigabit Ethernet (GbE). Hence, the home network is a convergence arena where the devices are able to communicate with each other and also with the service platforms. As a complement to these technologies, we must mention middleware opportunities such as universal plug and play (UPnP) and its associated certification alliance (Digital Living Network Alliance [DLNA]) that favors handset capability to interoperate, thereby offering simplicity in the user experience (automatic device discovery, automatic device interoperability).

Home network convergence is mainly built around the introduction of a home gateway. This equipment provides IP connectivity to devices for local data exchange and interconnection to service platforms. Some application capabilities can be added to routing capabilities, such as the introduction of a Session Initiation Protocol (SIP) feature that complements services handled in the core network by an IP multimedia subsystem (IMS) infrastructure (such new capabilities are management of local device registration or simultaneous service notification on devices).

ACCESS NETWORK CONVERGENCE

Access network convergence can either be achieved with convergence focusing on the transport layer and/or convergence involving the service control layer on the access network (the service control layer corresponds to network mechanisms in charge of delivering the service like call establishment for conversational services).

The first one is mainly driven by the reduction in operational expenditure (OPEX) costs. An example is to aggregate mobile access nodes into a backhaul network shared with a fixed access network, or more generally the use of a shared infrastructure for heterogeneous access solutions.

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This Long Term convergence built by the integrated operator is the integration of these four streams within its global strategy. Additional technologies fasten this seamless convergence between fixed and mobile environments.

Convergence at the service control layer allows access to the same service irrespective of the access network infrastructure.

CORE NETWORK CONVERGENCE

Core network convergence addresses convergence in the core network and is typically associated with the definition of a common framework able to handle any service invocations irrespective of the access network. The most relevant example is the specification of the IMS both specified in the 3G Partnership Program (3GPP), and endorsed by Telecommunications and Internet Converged Services and Protocols for Advanced Networks (TISPAN) of the European Telecommunications Standards Institute (ETSI) and the Next Generation Networks Global Standard Initiative (NGN GSI) of the International Telecommunications Union (ITU) [4]. TISPAN and NGN GSI specify access to the IMS platform installed in the core network from the fixed broadband access network, whereas 3GPP deals with access to IMS from a mobile access network.

The IMS is a core network infrastructure to control user sessions for the following services:

- Conversational services with multimedia components such as voice and video
- Real-time data-oriented services such as instant messaging and presence
- Audio-visual services, in the scope of specifications at ETSI (with TISPAN) and ITU (with IPTV GSI)

Some of the benefits expected by the operator deploying an IMS infrastructure are:

- To use a common functional infrastructure for services control while being as much access network agnostic as possible. A strong advantage in time to market (TTM) performance is also expected with efficient integration of services once the IMS infrastructure is deployed.
- Enhanced mechanisms to reserve bandwidth on the user data path as negotiated during session establishment between end-user handsets. This allows the operator to better control resources, especially significant in the mobile domain for packet switching (PS) services.
- Service triggering toward application servers in accordance with user service profiles.
- Solution for public switched telephone network (PSTN) renewal and expectations of OPEX/capital expenditure (CAPEX) reductions.

The implementation of an IMS infrastructure has impacts not limited to the core network but extended to the whole operator network: new capabilities in the terminal to support the SIP profile, updates of mobile gateways (like GGSN) to support a new interface for resource control, new application servers on an IMS to either handle SIP-based service logic or interwork with legacy service platforms (e.g., CAMEL-based for some mobile services), and finally on information systems (IS) for service provisioning.

APPLICATION SERVER LEVEL CONVERGENCE

Convergence at the service platform level (also called the application server level) can take two directions. First, it can be coupled with the introduction of a common control infrastructure such as IMS in order to address heterogeneous networks (fixed and/or mobile) from the same service platform with the capability to offer differentiated quality of service (QoS) to end users. This case can largely meet carrier grade strategies. The second direction is to consider it as a standalone convergence, as discussed below, and this strategy is supported by Web players.

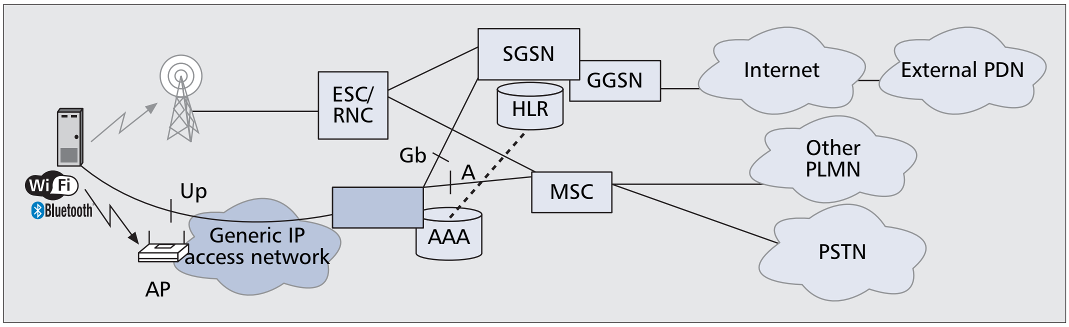
Standalone convergence allows service providers to benefit from generalized IP connectivity of terminals (fixed and mobile) to offer their services. This model is based on the Internet model with best effort QoS, unlike IMS, which allows the operator to set policy on QoS and charge for services accordingly. Note that this convergence proposed by the service providers (who do not generally own the network) can also be implemented in a decentralized way, also referred to as peer to peer (P2P). In the latter the user accesses his/her services (voice, IM, or content sharing) in a simple way: this decentralized application convergence only requires relying on the IP connectivity of the terminal and running the application on the terminal. A reduced number of centralized nodes need to be operated like an AAA server to control user access to paid services, interconnection of gateways to extend the service legibility to non-IP environments like the PSTN.

This long-term convergence built by the integrated operator (offering fixed and mobile services) is the integration of these four streams within its global strategy. Additional technologies fasten this seamless convergence between fixed and mobile environments. Such solutions are pointed out in the following section.

EXISTING SOLUTIONS TOWARD SEAMLESS CONVERGENCE

The past few years have witnessed tremendous growth in the number of wireless hotspots based on WiFi. Today, a large number of users access the Internet through wireless local area networks (WLANs) in a variety of places and environments, including their homes, offices, and public places. WLANs have emerged as a promising networking platform that offers high data rates to mobile users at low network deployment cost. Anyone can simply plug a WLAN access point to the Internet and make it available to wireless users to enjoy connectivity. Normally WLAN-based *hotspots* are deployed in areas with high user density and high bandwidth demands (e.g., in a town center). In contrast, base stations (BSs) in UMTS offer larger cells, and with inter-BS links, the UMTS provides nearly ubiquitous worldwide coverage. The interconnection of UMTS and WLAN networks provides an economical solution to offload some traffic from licensed to unlicensed spectrum technologies. Moreover, UMTS/WLAN cooperation provides an interesting blend, where the user can leverage the global coverage of UMTS and high data rate support of WLAN. The user can directly benefit from this cooperation through offers where the user may gain some data exchanges from Web portals for free when under WiFi coverage.

To this end, 3GPP Unlicensed Mobile Access



■ **Figure 1.** *GAN architecture and functional components.*

A major feature of GAN is to offer call continuity from a GAN capable terminal between a local area network terminating at the fixed access and the GSM infrastructure. Data services are also supported but are limited in throughput.

(UMA) and 3GPP Interworking-WLAN (I-WLAN) technologies offer a first step of convergence managed at the access network level.

Meanwhile, the integration of heterogeneous networks is supported in the core network by architecture like IMS [4] for user session control and potentially enriched with service platforms (e.g., Voice Call Continuity [VCC] or Multimedia Session Continuity [MMSC]) for internetwork mobility.

On the other hand, the media-independent handover (MIH) entity of IEEE 802.21 [5] is a flexible framework that does not intend to provide a standalone solution for fixed-mobile convergence (FMC), but rather assists the intertechnology handover decision and interoperability in coordination with other mechanisms.

In this section we discuss these complementary technologies by highlighting their respective design goals, architectures, and protocols.

UMA

UMA technology is designed to enable FMC in an access network. It is currently endorsed by the 3GPP [6] under the name generic aaccess network (GAN) (we use UMA and GAN interchangeably in the rest of this article).

A major feature of GAN is to offer call continuity from a GAN-capable terminal between a local area network (ultra wideband [UWB] or 802.11) terminating at the fixed access and the GSM infrastructure. Data services are also supported, but are limited in throughput since interconnection to the packet-switched core network (PSCN) is performed using the 3GPP-defined Gb interface. A recent evolution of GAN enriches user experience for data services with the enhanced GAN (EGAN) specifications (TR 43.902). The Gb interface is updated by the Gn interface to allow the enhanced GAN controller (GANC) entity to interconnect directly with the GPRS gateway service node (GGSN) entity. This evolution aims to reduce latency and overhead for PS services. No change on the circuit-switched domain is required. More precisely, UMA is today an available technology already deployed by certain operators like Orange with its Unik[1] offer.

In the GAN architecture an IPSec tunnel is established on the up interface between the GAN terminal and the GANC. This flow tunneling is a strong security requirement that allows conveying both signaling and user data flows (GSM/GPRS signaling and user plane flows are piggybacked into GAN-specific protocols and the IPSec tunnel) over an access network (named the generic IP access network) that is not supposed to be under the control of the mobile operator. The newly defined GANC entity reuses the already 3GPP-defined Gb and A interfaces to interconnect to the PSCN and circuit-switched core network, respectively. Note that the administration, authorization, and accounting (AAA) server is used to authenticate the GAN terminal when it sets up the secure tunnel. Figure 1 presents the architecture of GAN and its positioning with respect to the GSM/GPRS architecture.

I-WLAN

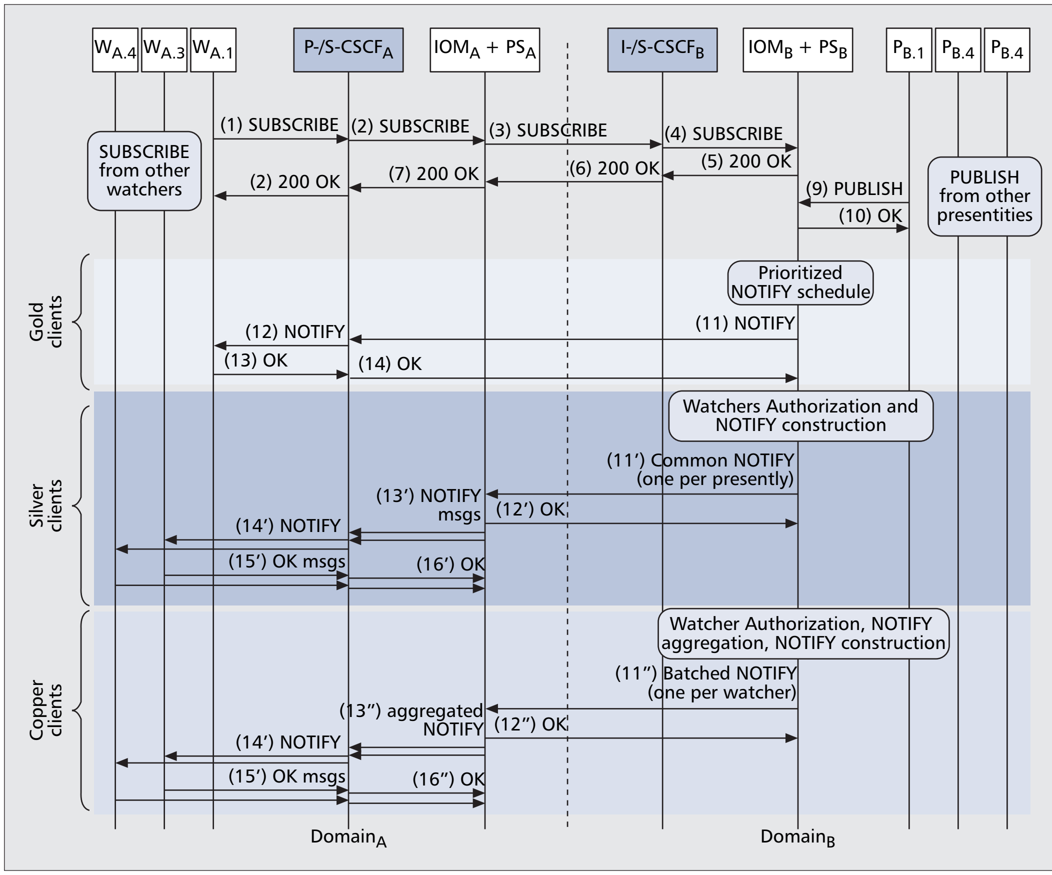
3GPP is developing interworking solutions between 3G and WLAN networks under the auspices of I-WLAN aiming to realize UMTS/WLAN integration [7, 8]. (I-WLAN is a 3GPP standard that intends to define an interworking architecture between a WLAN access network and the 3GPP core network.)

I-WLAN Architecture — In the 3GPP Release 6 specifications that aim at providing access to mobile operator services from a WLAN access network (AN), I-WLAN introduces three main components to achieve 3G/WLAN convergence : a wireless access gateway (WAG), a packet data gateway (PDG), and an AAA server, as shown in Fig. 2. The user equipment (UE) is typically dual-mode-capable: under WLAN coverage, it is capable of connecting to the WLAN AN using WiFi (as an example of radio technology) before attachment to the I-WLAN infrastructure, and when outside WLAN coverage, it can connect to the UMTS operator network. Data coming from UE through fixed ANs (generic IP access network in Fig. 2) are aggregated at the WAG, which is further connected to the PDG. In the roaming case, the visited WAG is also able to route packets toward the home domain of the operator to which the user has subscribed. The PDG in the I-WLAN architecture works as a gateway toward either external packet data networks (PDNs) or the operator service infrastructure, as shown in Fig. 2. The PDG also interacts with the AAA server to perform service-level AAA functions.

When entering into the coverage area of a WLAN AN, the UE triggers its attachment procedure with the I-WLAN infrastructure; thus, an IPSec tunnel is established between the UE and

[1] *Orange Unik™ (http://unik.orange.fr)*

When entering into the coverage area of WLAN AN, the UE triggers its attachment procedure with the I-WLAN infrastructure and thus an IP Security (IPSec) tunnel is established between the UE and the PDG.



■ **Figure 2.** *I-WLAN R6 architecture and functional components.*

the PDG. Packet-switched (PS) domain signaling and user plane data are carried into this secure tunnel over a Wu interface.

I-WLAN Protocols — The protocol stack between the WLAN UE and the PDG is depicted in Fig. 3. The protocol layers introduced in the I-WLAN stack are:

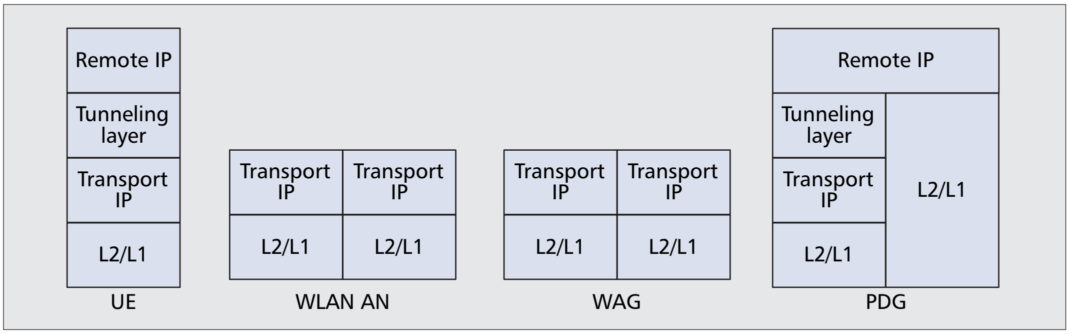
- Remote IP layer: The remote IP layer is used by the WLAN UE to communicate with the external PDN. The PDG routes the remote IP packets without modifying them.
- Tunneling layer: The tunneling layer consists of a tunneling header (IPSec), which allows end-to-end tunneling between WLAN UE and a PDG. It is used to encapsulate remote IP layer packets. The tunneling header contains the information which is further required by the PDG and the UE to decrypt the IP packets.
- Transport IP layer: The transport IP layer is used by the intermediate entities/networks and WLAN AN in order to transport the remote IP layer packets encapsulated into the IPSec tunnel.

I-WLAN Evolution — On the core network side, a new work item called System Architecture Evolution (SAE) was defined. In this evolved UMTS architecture it is expected that IP-based services will be provided through various access technologies. A mechanism to support seamless mobility between heterogeneous access networks is needed for future network evolution. To this end, I-WLAN is included in the SAE to ensure a smooth migration path from the R6 I-WLAN work to a generic multi-access solution. Thus, mobility is under study for I-WLAN in release 8 and is based on Mobile IP (MIP) unlike the legacy GPRS systems with GTP-based mobility in the core network (UMA also uses this GTP mobility since interconnecting to the GPRS core network). The mobile device is requested to integrate a DSMIPv6 stack that dialogs with a home agent entity (located in the core network) that is in charge of routing user data flows toward the ANk where the user is attached to.

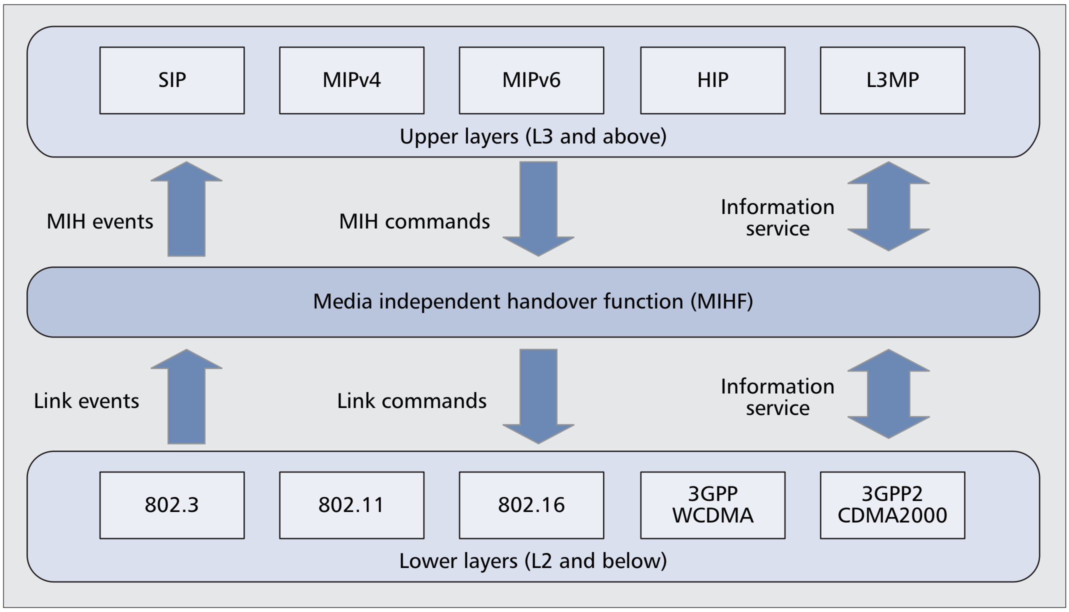
MIH: IEEE 802.21

The IEEE 802.21 Working Group (WG) defines MIH in order to offer seamless convergence across heterogeneous networks [5]. The MIH defines a framework to support information exchange that facilitates mobility decisions, as well as a set of functional components to execute those decisions. The MIH shields link-layer heterogeneity and provides a unified interface to upper-layer applications in order to support transparent service continuity. The handover scenarios considered in 802.21 WG include wired as well as wireless technologies — the complete IEEE 802 group of technologies and 3GPP/3GPP2 AN standards.

The MIH framework provides methods and procedures to gather useful information from the mobile terminal and network infrastructure



■ **Figure 3.** *I-WLAN R6 protocol stack.*



■ **Figure 4.** *MIH architecture and functional components.*

Analogous to MIES, MICS can also be divided into two categories i.e., MIH commands and link commands. Both of these types of command follow the same principle as described for MIES.

in order to facilitate handover between heterogeneous access networks. MIH provides network discovery procedures that help the mobile terminal determine available networks in its current neighborhood. A mobile terminal selects the most appropriate network with the help of the gathered information such as link type and quality, application class, network policy, user profile, and power constraints.

MIH Architecture — MIH function (MIHF) lies at the heart of the MIH architecture and provides an intermediary or a unified interface between the lower-layer heterogeneous ANs and higher-layer components.

MIH provides generic access-technology-independent primitives called service access points (SAPs). SAPs are application programming interfaces (APIs) through which the MIHF can communicate with the upper and lower layer entities.

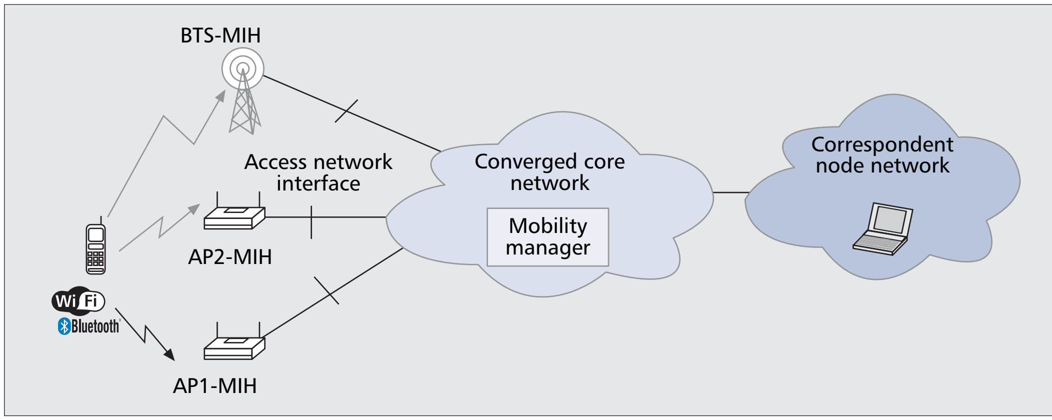
The MIHF facilitates three services: media-independent event service (MIES), media-independent command service (MICS), and media-independent information service (MIIS). As highlighted in Fig. 4, those services are responsible for:
- Signaling state changes at lower layers
- Control by higher layers
- Provision of information regarding the neighboring networks and their capabilities, respectively

MIH Functional Components — In the following we describe the MIH functional components in greater detail.

MIES — It notifies the upper layers of the occurrence of lower-layer events (triggers) in order to optimize handover performance. The events can be local (i.e., within a mobile client) or remote (i.e., sent by the network component). The event model follows the notification/subscription principle. Since events are advisory and not mandatory, registration to a specific event is needed for an entity to be notified whenever such an event occurs.

MIES events may be broadly classified into two categories: link events and MIH events. Both link and MIH events typically flow from a lower layer to a higher layer. Link events are defined as events originating from event source entities below the MIH function and typically terminate at the MIH function. Within the MIHF, link events may be further propagated, with or without additional processing, to upper layer entities that have registered for the specific event. Events that are propagated by the MIH to

I-WLAN is an alternative solution to UMA aiming at integration of UMTS core networks and WLAN. It is designed for packet-based services and is targeting a more long term evolution than UMA.



■ **Figure 5.** *MIH potential integration with the current network architecture.*

the upper layers are defined as MIH events. Some of the common events include `Link Going Down`, `L2 Handover Imminent`, and `Link Parameters Change`. Upon reception of a certain event, the upper layer makes use of the command service to react to the change in the network state.

MICS — MICS refers to commands sent from higher layers to lower layers in the MIH framework. MIH commands are used to subscribe to certain information from the lower layers such as gathering information about the status of connected links, as well as execute higher-layer mobility and connectivity decisions at the lower layers. Similar to MIH events, commands can also be local or remote.

Analogous to MIES, MICS can also be divided into two categories: MIH commands and link commands. Both of these command types follow the same principle described for MIES. Some of the common commands include `MIH Poll`, `MIH Scan`, `MIH Configure`, and `MIH Switch`.

MIIS — It is used by a mobile node or network entity to discover and obtain information about neighboring networks. The purpose of the information service is to acquire a global view of the heterogeneous networks to facilitate seamless handover across those networks. For instance, when a mobile node is about to move out of the coverage of the current network, it queries the network (MIIS) about the available neighboring networks in order to optimize the handover process. MIIS provides access to both static and dynamic information. The static information may include names and providers of the neighboring networks. Examples of dynamic information include channel information, MAC address, and security information. MIIS stores the information in a standardized format such as ASN.1 or XML.

Limitations and Potentials

The objective of this section is to provide a comprehensive comparison between convergence techniques by illustrating their advantages and limitations.

UMA presents a relevant solution in the short and mid terms for voice service over a circuit-switched core network with GSM-like performance for voice handover. However, it is worth noting that UMA has many limitations, notably the significant overhead due to the complexity of the protocol stack at the terminal (with upper layers of GSM/GPRS protocol stack over new UMA protocol stack for circuit-switched [CS] and PS domains, respectively). UMA also suffers from poor performance in packet mode, and evolution toward EGAN (enhanced GAN) is considered to overcome this weakness. Some mechanisms for QoS handling like DSCP marking can be implemented by operators to manage QoS in the home network and ANs (up to the mobile core network domain), but the use of IPsec tunnel sets constraints on marking rules, especially when GAN is a bearer for multiservices with different QoS needs. Finally, UMA also requires the use of a new terminal for the end user to access FMC services built over this technology.

I-WLAN is an alternative solution to UMA aiming at integration of UMTS core networks and WLAN. It is designed for packet-based services and is targeting a more long term evolution than UMA. Indeed, enhancements with 3GPP Release 8 (R8) specifications on I-WLAN are intended to support mobility and have been released with the first stable SAE specification.

This mobility based on MIP can be seen as a first step in mobility management. Indeed, it allows data transfer either between I-WLAN accesses or from I-WLAN access toward a cellular network (and conversely) for services like Web browsing or content streaming. For services controlled by IMS (like voice over IP in I-WLAN), more advanced use cases for mobility will be expected and be delivered with additional features available from IMS as explained hereafter.

Indeed, a weakness of I-WLAN is the lack of support for circuit-based services. Consequently, the operator is required to couple I-WLAN deployment with an IMS infrastructure with a VCC enabler to support call handover with legacy CS networks (typically GSM) and an MMSC enabler to manage session transfer for multimedia services. 3GPP has gathered in R8 framework these two former concepts within the IMS service continuity (ISC) concept [9]. Some

	GAN/UMA	I-WLAN	802.21/MIH
Standardization body	3GPP	3GPP	IEEE
Mobility performance	++: Applied to circuit-switched and packet-switched services ++: Integration effort reduced (in-built mobility solution)	+: Under study (MIP-based) and applicable to packet-switched services only –: Need for integration effort with IMS infrastructure for enhanced mobility use cases (referring to ISC [9])	++: Under study and applicable to packet-switched services and circuit-switched. Interworking with broadcast networks is under investigation.
Security	++: EAP-based user authentication (EAP SIM, EAP AKA), use of IPSec on transport plane	++: EAP-based user authentication (EAP SIM, EAP AKA), use of IPSec on transport plane	+: EAP protocol between the mobile node and its point of attachment (e.g., MIH-AP in Fig. 5), and AAA protocol to the authentication server.
Network complexity for deployment	++: Network impacts reduced: limited number of new nodes, legacy protocols (GSM,GPRS) largely reused	++: Network impacts reduced: limited number of new nodes	+: The impact on the network varies with regards to the approach used (terminal-oriented, network-oriented, or hybrid). Nevertheless, the impact on the network is limited even in the network-centric approach.
Handset impact	– –: New handset required	–: Software update possible for open OS but potential issue on quality of integration	–: Software update required at different networking stacks (3GPP, 802.x, …) in both terminal-centric and hybrid approaches. Limited impact in the network-centric deployment.
Billing	+: Supported	+: Supported	– –: Out of scope
Legend: ++: Strong advantage; +: Advantage; –: Drawback; – –: Strong drawback			

Table 1. *Comparison of technologies for seamless convergence.*

issues are still outstanding, like the dynamic provisioning of operator policies within the mobile handset.

Like GAN, I-WLAN suffers from certain limitations on QoS handling due to an always activated IPSec tunnel that hides the nature of each encrypted data packet along with the fixed access network. Some additional mechanisms exist to counter this limitation by propagating the DSCP value (used for flow prioritization by IP routers) out of encrypted headers of IPSec packets. But this always activated IPSec tunnel feature is not optimized, especially when the same operator controls the fixed access network and the mobile network, since in this case encrypting flows is not justified.

Unlike UMA, I-WLAN appears less constraining on handset implementation since some vendors propose to download I-WLAN client software on their smart phones to become I-WLAN-capable. However, this update may suffer from a lack of integration that is not convenient for high end-user experience.

MIH is an interesting approach for interoperability with respect to long-term network architecture evolution. It provides mechanisms for improving handover decisions and mobility policy (e.g., what kind of service the user is allowed, to which AN the user is allowed to attach, what QoS is expected) for services supported over both PS and CS networks. Mobility handling can be triggered and enforced by either the network or the terminal. The major point to highlight here is that the mobility procedure remains under the control of the network operator, whereas the interaction with the service platform is considered out of the scope of the standard.

MIH, as a generalized framework for mobility, can benefit the mobility policy in a 3GPP architecture context. A potential architecture for integration of MIH with the current network architecture is shown in Fig. 5. Indeed, some MIH functions can provide complementary information to that sent by the mobile terminal for handling user mobility. In particular, the 3GPP standardization committee has put forth several requirements related to non-3GPP mobility support, and the committee recognizes that the network-based mobility scheme needs some form of media independent mobility signaling to coordinate the access change between networks. From this perspective, some MIH functions, such as those related to the generation of MIH events, can be inserted into some access points composing the convergence network of the operator. This location of MIH functions within the network acts as a complement to integrating MIH functions within devices. For example, the home gateway (as defined previously) can provide the mobility manager located in the converged core network complementary information not available at the terminal side and necessary for optimized mobility management. The available bandwidth on the radio interface used by the considered mobile is an example of such complementary information. The evolution of the home network architecture is indeed raising

Seamless convergence of heterogeneous access networks is essential in today's telecommunication systems. Accordingly, operators can provide telecommunication services without worrying about user's location, access technology, or device.

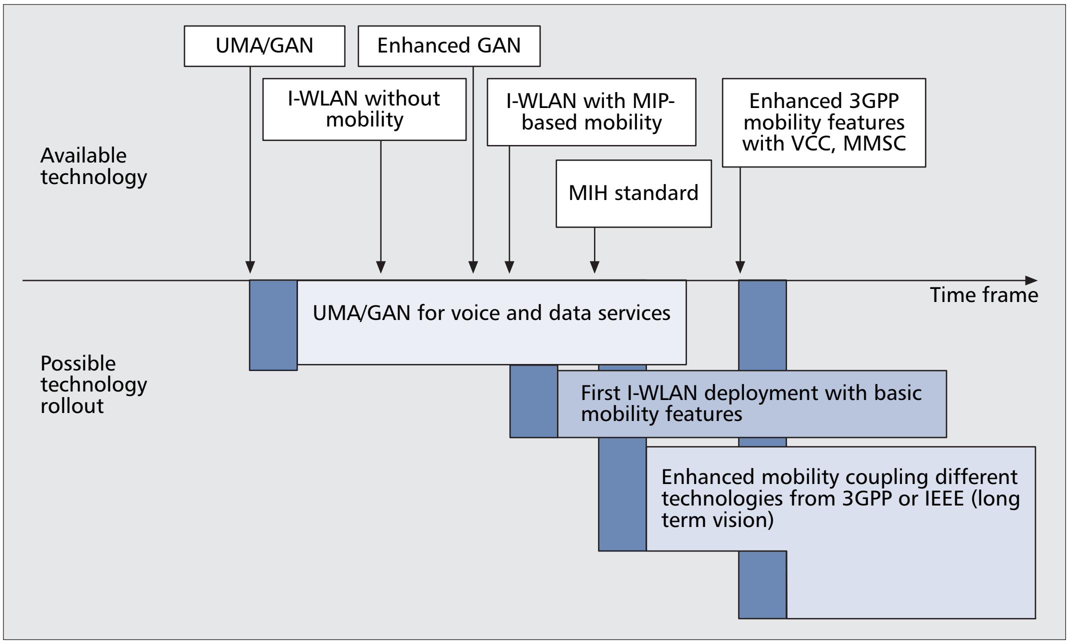


Figure 6. *Timeframe proposal for fixed/mobile convergence solutions deployment.*

new requirements, and a global view of the state of resources in the home network is needed for better mobility management.

A number of issues are still to be addressed in order to integrate MIH capabilities with existing 3GPP mechanisms.

The first issue concerns the methods for conveying reports of MIH events from the access points up to the mobility manager. In the context of previous 3GPP technologies (GAN and I-WLAN), strong security constraints are set to interconnect with the mobile infrastructure. Two possible approaches are considered: access through the secure gateway (SEGW) or a direct interconnection with the mobility manager. The first approach is similar to the security requirement set for a terminal with an IPSec tunnel establishment coupled with terminal authentication. The second approach is more appropriate in a trusted environment involving the mobile operator and the AN operator.

The second issue concerns the correlation of the reports of MIH events with reports generated by the mobile terminal. This issue is associated with the location management in order to correlate MIH event reports from a given access point with the reports of terminals attached to this same access point.

A third issue is related to the actor model and associated regulation statements. The actor model stands for identifying all operators that participate in the service delivery. It encompasses, for instance, the access network provider, service control provider, and content provider in the case of audiovisual services. An example of regulation constraints is given hereafter.

Today, WiFi access points in home networks are generally integrated in the home gateway, which is the equipment under the control of operator. Moreover, the WiFi access point is presently transparent regarding mobility policy as it is not involved in triggering events for mobility management. A potential regulatory issue can be raised when allowing interconnection of fixed operator controlled equipment (the home gateway) with the mobile operator infrastructure to convey MIH information in order to improve mobility performance. In this latter case, these MIH-based enhanced mechanisms must be reproducible to third parties that wish to deliver mobility solutions. These third parties must be able to benefit from these same MIH-based inputs to enforce mobility decisions when their customers are attached to this WiFi access point.

Table 1 provides a comparison of the various convergence technologies discussed in this article.

A possible strategy for a mobile operator to define its mobility architecture can be:

- The assumption made on the trigger for I-WLAN deployment as technology renewing UMA/GAN is the capability of I-WLAN to support user mobility. This requirement for mobility is more constraining than with UMA/GAN, especially for voice services since it has to be correlated with the introduction of IMS to control VoIP and multimedia user sessions. For this purpose QoS handling for VoIP services over mobile networks remains a major challenge today.
Note that I-WLAN rollout can be hastened by operators when no mobility feature is required.
- The mobility between the GSM and I-WLAN systems will be performed first with VCC for voice services only, and then be enriched with MMSC for enhanced services coupling voice and data. An enhanced use case for a user with an ongoing multimedia session with voice and video components on his/her handset and entering his/her home network is: the voice component can be maintained on his handset, whereas the video component is split and displayed on the TV screen.

Figure 6 presents a possible timeframe for the adoption of FMC solutions by network operators. From the figure, MIP mobility is suited for data services like Web browsing or content streaming, VCC mobility for voice services controlled by IMS between CS and PS networks, and MMSC mobility for multimedia services controlled by IMS.

The enhanced mobility step begins when the operator takes advantage of hybrid-like solutions that blend the benefits of each technology (e.g., those standardized by 3GPP or IEEE) to build mobility architecture with enhanced policy decisions or enhanced mobility triggers (referring to MIH events).

Conclusion

We present an overview of network convergence coupled with the services and their levels of integration as well as possible impacts on the network architecture. A comprehensive survey of different standardized seamless convergence solutions is discussed with an in-depth observation of their potential benefits and limitations. The ultimate goal of this study was to assess different mid- to long-term architectural scenarios for convergence of heterogeneous access networks. Particular emphasis was on terminal seamless mobility between different access networks, ensuring continuity of service even for the most stringent types of applications.

Seamless convergence of heterogeneous access networks is essential in today's telecommunication systems. Accordingly, operators can provide telecommunication services without worrying about user location, access technology, or device. In fact, seamless convergence avoids the problems of maintaining multiple networks, which obviously creates interoperability issues and complicates maintenance, support, and upgrading. In addition, it provides the opportunity for fixed-only operators to defend their business against the current trend toward mobile/nomadic services, and also enables integrated operators (offering both fixed and mobile services) to avoid developing separate facilities for each type of network. In contrast, the seamless convergence of heterogeneous access technologies enables network operators to offer enhanced services and better user experience. It is also worth mentioning that seamless convergence was discussed within several industry dominated projects, for instance, Daidalos[2] and Ambient,[3] among others.

To complete the convergence puzzle, if today's approaches are mainly focused on integrating WLANs with UMA and I-WLAN as a short- and mid-term solution, focus in the distant future might be to integrate cellular and non-cellular technologies. MIH coupled with mobility protocols at the higher layers (DSMIPv6 on the handset or Proxy MIP on the network for handset without MIP capabilities) and in coordination with IMS throughout VCC or MMSC application servers could indeed be the future of seamless convergence enabled network architectures.

The enhanced defined mobility corresponding to the long-term vision could be structured around hybrid-like solutions that both blend advantages of different technologies specified by different standardization bodies (e.g., 3GPP, IEEE) and also are not limited to the scope of specification for each technology. As an instance of this latter case, coupling access to a mobile network (through UMA or I-WLAN technologies) with a simultaneous openness to the home network permits new usage for the end user when entering the domestic area. Connectivity to the home network gives the user access to his/her fixed driven services (e.g., local content exchange, local media transfer within an ongoing session), and connectivity to the mobile network offers reachability whatever the user's mobility status. These examples enforce the promise of being not only always connected, but always best connected.

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[2] IST Daidalos project; http://www.ist-daidalos.org

[3] IST Ambient Network project; http://www.ambient-networks.org/

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