# TRENDS IN THE CONVERGENCE OF WIRELESS NETWORKS

**Daniel SORA**

The Regional Department of Defense Resources Management Studies, Brasov, Romania

*In today's technological market, there are many types of networks. These networks include wireless personal area networks (WPANs), wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), and cellular networks. A vision of a future convergence of networks envisaged for WPANs, WLANs, WiMax, and cellular networks is presented in this paper.*

**Key words:** *wireless, networks, convergence, standards, mobile, interoperability.*

## 1. INTRODUCTION

In today's technological market, there are many types of networks. These networks include wireless personal area networks (WPANs), wireless local area networks (WLANs), wireless metropolitan area networks (WMANs), and cellular networks.

In general, the range coverage of WPANs is smaller than that of WLANs, and that of WLANs is smaller than that of cellular networks. Between WMANs and cellular, their range coverage depends on the frequency band in which they are operating. In each type of network, there are also different categories of networks. For example, there are ZigBee, Bluetooth, WiMedia, and IEEE 8022.15.3c networks in WPANs.

IEEE 802.11 WLANs can be further classified as IEEE 802.11a, IEEE 802.11b, IEEE 802.11g, and draft IEEE 802.11n. These WLANs differ in the data rates that they can deliver. Worldwide interoperability for microwave access (WiMax) is an example of WMAN. On the other hand, cellular networks can be divided into different generations. The first generation (1G) cellular networks are mostly no longer in use. A commonly used second-generation (2G) cellular network today is the global system for mobile communications (GSM). An enhancement of the GSM is the 2.5G general packet radio service (GPRS) cellular network. A third-generation (3G) cellular network in universal telecommunications systems (UMTSs) is the wideband code-division multiple access (WCDMA) network. Enhancement of the WCDMA is the 3.5G high-speed packet access (HSPA). In North America, there are 2G IS-95 cellular networks and 3G CDMA2000 cellular systems. Another cellular network being standardized is the 3.9G long-term evolution (LTE).

Each of these networks is designed to deliver specific services. These services cannot be migrated to other types of networks. However, there are some bodies that address the needs whereby services can roam from one network to another network based on the best connection available. For example, a local area network (LAN) may be the best connection to the Internet in a fixed office environment. However, a WLAN may be a better option when users need to move from their office to a meeting room. If a user needs to be out of the office most of the time and is often “on the go,” he or she may stay connected through a mobile phone or personal digital assistant (PDA). Thus, it would be very convenient for a user if the services she is using can be continued in any environment, whether she is in the office, a meeting room, or out of the office. The mobile device should have a multi-radio that automatically connects the user to the best available network without loss of the service’s session during vertical handoff and without intervention. Vertical handoff is the handling of connection from one network to another network that supports a different transmission rate. Thus, interworking is needed between different access networks. A few of these bodies that address the interworking mechanisms are the third-generation partnership project (3GPP), IEEE 802.11u, and IEEE 802.21. 3GPP evolved from the GSM and GPRS cellular networks.

IEEE 802.21 introduces a 2.5 layer between the second and third layers in the OSI/ISO model. The 2.5 layer introduces the media-independent handoff. The aim of this standard is to enable seamless handoff and interoperability between heterogeneous network types, which include both IEEE 802 and non-IEEE 802 networks.

## 2. 3. GPP/WLAN INTERWORKING

In this form of interworking [1], 3GPP refers to the third-generation partnership project, which evolved from 2G GSM and 2.5G GPRS cellular system; WLAN refers to IEEE 802.11a/b/g wireless local area networks. Both cellular systems and WLANs are widely deployed in the world today. To provide a seamless experience for a mobile device, interworking mechanisms between cellular systems and WLANs are needed to provide smooth vertical handoff in more complex interworking scenarios.

## 3. IEEE 802.11u INTERWORKING WITH EXTERNAL NETWORKS

The IEEE 802.11u standard is currently under standardization. The aim of this standard is to amend IEEE 802.11 to add features that will improve interworking with external networks. The interworking between IEEE 802.11 WLAN and external networks is achieved through medium access control (MAC) enhancements.

IEEE 802.11u addresses such areas as enrollment, network selection, emergency call support, user traffic segmentation, and service advertisement.

## 4. LAN/WLAN/WIMAX/3G INTERWORKING BASED ON IEEE 802.21 MEDIA-INDEPENDENT HANDOFF

The IEEE 802.21 standard is being standardized. The aim of this standard is to enable seamless handoff and interoperability between heterogeneous network types. These heterogeneous network types include both IEEE 802 networks and non–IEEE 802 networks. The IEEE 802 networks are the IEEE 802.3 local area network (LAN), IEEE 802.11 wireless LAN (WLAN), and IEEE 802.16 wireless metropolitan area network (WMAN). The LAN is Ethernet, while the WLAN is Wi-Fi. On the other hand, the WMAN is WiMax. The non-IEEE 802 networks are cellular networks from 3GPP and 3GPP2. 3GPP supports a 3G UMTS, and 3GPP2 supports 3G CDMA2000.

UMTS evolved from 2G GSM and 2.5G GPRS; CDMA2000 evolved from the North America Standard IS-95. The fundamental assumption in the standard is that the mobile devices can support multiple radio interfaces, both wired and wireless, such as Ethernet, Wi-Fi, Bluetooth, WiMax, GSM, GPRS, UMTS, and CDMA2000.

The seamless handoff and inter-operability between heterogeneous network types is achieved by introducing a conceptual layer 2.5. In the traditional OSI/ISO model, layer 1 is the physical layer, and layer 2 is the link layer, consisting of the data link sublayer and the medium access control (MAC) sublayer. Layer 3 is the network layer. This conceptual layer 2.5 is specified by the media independent handoff (MIH) function. **Figure 1** shows IEEE 802.21 architecture, specifically the interactions between the IEEE 802.21 MIH function and other protocol stack elements.

In IEEE 802.21, one of the main ideas is to provide a common interface for managing events and control messages exchanged between network devices [2]. The outcome of the standard is to provide a general framework applicable from the management and control paradigms of each specific technology and a common interface to the upper layers [2]. These upper layers include the network layer up to the application layer. Besides these functionalities, the standard also introduces an information system (IS) for the storage, management, and communication of system-wide network information [2].

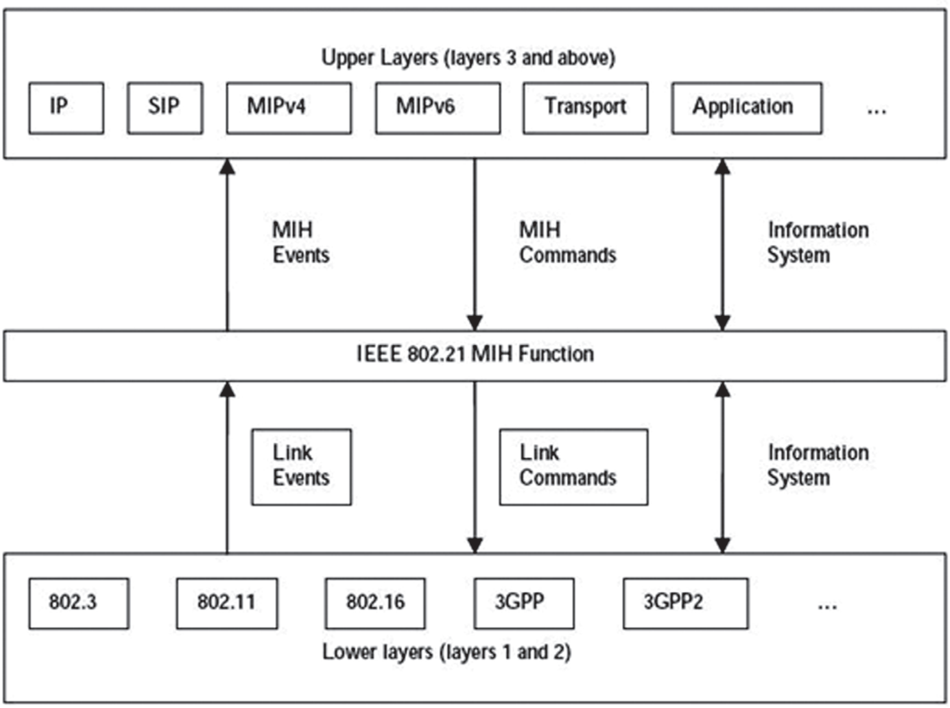


**Fig. 1.** *IEEE 802.21 architecture*

The IEEE 802.21 MIH function defines three services [3]:

1. Media-independent event service (MIES);

2. Media-independent command service (MICS);

3. Media-independent information service (MIIS).

The MIES provides services to the upper layers of a mobile device by notifying both local and remote events [3]. Local events occur within the local stack of the mobile device, while remote events occur in the IEEE 802.21 MIH function of another mobile device in the network. The event is based on a subscription and notification procedure. The upper layer protocols (layer 3 and above) register a certain set of events to the lower layers (layers 1 and 2) through the IEEE 802.21 MIH function, and they will be notified as these events take place [3]. Information on local events is passed from the lower layers to the higher layers through the IEEE 802.21 MIH function. Information on remote events can be passed to and from the IEEE 802.21 MIH function or layer 3 (L3) mobility protocol in a remote stack. Some common events that are provided by the IEEE 802.21 MIH function are as follows:

- Link up
- Link down
- Link parameters change
- Link going down
- Layer 2 (L2) handoff imminent

The MICS provides primitives to the higher layers to control the functions of the lower layers [3]. MICS commands are used to gather information about the status of the connected links. These commands are also used to execute higher layer mobility and connectivity decisions to the lower layers. Furthermore, these commands can be local and remote. Moreover, these commands can be from the higher layers to the IEEE 802.21 MIH function or from the IEEE 802.21 MIH function to the lower layers. Some examples of these commands that are incorporated in the IEEE 802.21 MIH function are as follows:

- MIH poll
- MIH scan
- MIH configure
- MIH switch

These commands instruct an IEEE 802.21 MIH mobile device to poll connected links to learn their up-to-date status, to scan for newly discovered links, to configure new links, and to switch between available links [3].

The MIIS defines information elements and corresponding query-response mechanisms. These elements and mechanisms allow the IEEE 802.21 MIH function to discover and obtain information and distribute within a geographical area network information relating to nearby networks [2,3]. The role of MIIS is to provide as much information as possible to the mobile devices on the networks available and the services that they can provide [2]. Furthermore, the MIIS provides the link to access information that is helpful to handoff decisions [3]:

- Network type
- Roaming partners
- Service providers of the neighboring networks
- Channel information
- MAC addresses
- Security information
- Other information on the higher layers.

This information can be made available through the upper and lower layers. The MIIS uses a standard, platform-independent description language to represent the information [2]. External markup language (XML) and type length value (TLV) are two such examples. The information gathered by MIIS can be static or dynamic [2].

Examples of static information are the names and providers of the mobile device's neighboring network; examples of dynamic information are the information on the channel, the security, and the MAC addresses. In some scenarios, some layer 2 information may not be available, or not enough is available to make intelligent handoff decisions. In these cases, upper layers' services may be needed to help in making the decision.

There are two advantages of MIIS: that the information it provides can help significantly in the definition of high-level handoff decisions and policies [2], and that specific access-dependent discovery methods for automatic detection of neighboring networks are avoided.

The IEEE 802.21 standard does not specify rules or policies for handoff decisions and does not dictate that the handoff be a network or mobile-controlled handoff [4].

Concrete rules and policies are beyond the scope of the IEEE 802.21 standard, and their definition and specification are up to the wireless service provider [4].

## 5. FUTURE CELLULAR/ WIMAX/ WLAN/WPAN INTERWORKING

3GPP is considering cellular networks and WLANs interworking, while IEEE 802.21 is considering a media-independent handoff between LAN, WLAN,WiMax in IEEE, and cellular networks in 3GPP and 3GPP2. We envisage that other technologies for WPANs, such as

Zigbee, Bluetooth, and WiMedia, will also be integrated together with LAN, WLANs, WiMax, GSM, GPRS, UMTS, IS-95, CDMA2000, HSPA, and LTE cellular networks, as shown in Figure 2.

ZigBee is a WPAN that targets applications that require a low data rate, long battery life, and secure networking. ZigBee uses IEEE 802.15.4 specifications. Bluetooth, which is also a WPAN, is used to connect such devices as mobile phones, computers, digital cameras, videogame consoles, and printers over a secure short range unlicensed band. WiMedia is also a WPAN but can support a much higher data rate, up to 480 Mbps. The IEEE 802.15.3c draft and ECMA TC 48 mm Wave draft both operate in the 60-GHz range, and both use directional medium access control (MAC). The IEEE 802.15.3c draft MAC is an extension of the IEEE 802.15.3 MAC, and the ECMA TC 48 mm Wave draft MAC is an extension of the WiMedia ECMA-368 MAC.

IEEE 802.11 is a commonly used WLAN. IEEE 802.11b supports a data rate of up to 11 Mbps, while IEEE 802.11a and IEEE 802.11g support a data rate of up to 54 Mbps. The IEEE 802.11n draft standard supports a data rate of up to 600 Mbps.

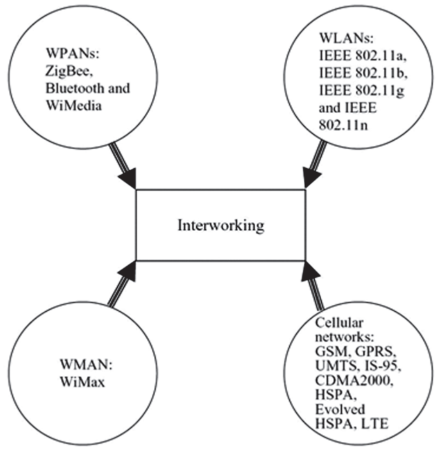


**Fig. 2.** *Future cellular/WiMax/WLAN/WPAN interworking*

WiMax is a WMAN based on IEEE 802.16. It is used as a last-mile wireless broadband access alternative to cable and digital subscriber line (DSL).

GSM is a second-generation (2G) cellular network; GPRS is a 2.5G cellular network. UMTS is a third-generation (3G) cellular network that uses wideband code-division multiple access (WCDMA) as the multiple-access technology. IS-95 is a 2G code-division multiple access (CDMA)–based cellular network, and CDMA2000 is a 2.5G/3G CDMA standard. HPSA is a 3.5G cellular network designed on top of WCDMA. LTE is a 3.9G cellular network.

The convergence of networks will give rise to many technical challenges. Some of these challenges include quality-of-service issues, traffic class mappings among different access technologies, vertical handoff mechanisms between access technologies, protocol stack designs, AAA, service discovery mechanism, and routing. Issues in 3GPP/WLAN interworking and IEEE 802.21 media-independent handoff will certainly arise in the convergence of networks that is envisaged.

One of the fundamental factors in the access technologies is data rate. **Table 1** shows the data rates for various access technologies. Due to the different data rates in the access technologies, some services may be terminated during vertical handoffs between access technologies. Rate-adaptive services are also needed when services move from one access technology to another.

**Table 1.** Data rates for various access technologies

| Access Technology | Data Rate |
|---|---|
| ZigBee | Up to 250 kbps |
| Bluetooth | Up to 1 Mbps |
| WiMedia | Up to 480 Mbps |
| 802.15.3c | Up to 6 or 7.35 Gbps |
| ECMA TC48 mmWave | Up to 6.478 Gbps |
| WLAN | |
| 802.11b | Up to 11 Mbps |
| 802.11a | Up to 54 Mbps |
| 802.11g | Up to 54 Mbps |
| 802.11n | Up to 600 Mbps |
| GSM | Up to 9.6 kbps |
| IS-95 | Up to 9.6 kbps (mandatory support) |
| GPRS | Up to 117 kbps |
| UMTS | Up to 2 Mbps |
| CDMA2000 | Up to 2 Mbps |
| WiMax (fixed broadband wireless access) | In excess of 120 Mbps |
| HSPA | Up to 14.4 Mbps downlink/5.76 Mbps uplink |
| Evolved HSPA | Up to 42 Mbps downlink |
| LTE | Up to 100 Mbps downlink/50 Mbps uplink |

Mappings of traffic classes between access technologies are dependent on the traffic classes available in each technology. ZigBee has two traffic classes: one based on a contention period (CP), the other based on a contention-free period (CFP) or guaranteed time slot (GTS). The former is based on CSMA/CA and is for non-realtime traffic; the latter is based on reservation and is for real-time traffic. Bluetooth can support voice and data traffic based on polling. WiMedia has four access categories in its prioritized channel access (PCA) mode, and real-time traffic can use its distributed reservation protocol (DRP) mode. The four access categories in PCA are background, best effort, video, and voice traffic. Similarly, IEEE 802.11e EDCA has four traffic access categories: background, best effort, video, and voice. WiMedia PCA is derived from IEEE 802.11e EDCA. Cellular networks 2G and above can support at least voice and data. UMTS can support four traffic classes: background, interactive, streaming, and conversational. WiMax can support at least four scheduling services: best effort, non-real-time polling, real-time polling, and unsolicited grant. Thus, it may not be possible to have one-to-one mapping of traffic classes across all the access technologies.

The types of handoffs in different access technologies are also different. IEEE 802.11 WLAN uses hard handoff; that is, a connection is broken before a new connection is made: break before make handoff. GSM and GPRS cellular networks also use hard handoff, while 2G and 3G CDMA-based cellular networks such as IS-95, CDMA2000, and WCDMA in UMTS use soft handoff. A new connection is made before breaking the old connection in soft handoff, also known as make before break. On the other hand, LTE cellular network uses hard handoff. Thus, different horizontal handoff within each type of access technologies will make the design of vertical handoff between heterogeneous networks challenging.

New protocol stack design such as IEEE 802.21 media-independent handoff will certainly help to alleviate the vertical handoff issues. IEEE 802.21 media-independent handoff should be expanded to include access technologies that are not being considered at the moment as well as future access technologies.

New AAA scenarios also need to be studied to address security, charging, and access. Different access technologies also have different security procedures before a mobile device is granted access. The security architecture and protocol in IEEE 802.11 is called wired equivalent privacy (WEP). WEP is responsible for providing authentication, confidentiality, and data integrity. Authentication is the process of verifying that a mobile station or user requesting access is, in fact, a legitimate user.

Confidentiality is achieved by sharing a secret key on how to encrypt and decrypt messages. The secret key is the method or algorithm or cipher that the mobile station and the access point use to decrypt messages. Integrity ensures that the message sent by the source to the destination has not been modified or tampered with. GSM uses a 128-bit preshared secret key for securing the interface between the mobile device and the base station. This key is also stored in the authentication center (AuC), which is a database that stores the secret keys of all subscribers. The secret key stored in the SIM card of the mobile device and the AuC forms the foundation for securing the GSM access interface.

GPRS uses the wireless application protocol (WAP). WAP is an open specification that offers a standard method to access Internet-based services and contents. An end-to-end security is achieved by wireless transport layer security (WTLS) in the WAP stack. There is also no key establishment in UMTS. UMTS also uses a 128-bit preshared secret key between the USIM card of the mobile device and the AuC.

Bluetooth uses a large number of keys in its security process. The key hierarchy depends on whether it is unicast or broadcast communication. WiMedia uses a four-way handshaking procedure for two devices to establish pairwise temporal keys (PTKs) and a secure relationship [5]. A device may solicit or distribute group temporal keys (GTKs) within a secure relationship [5]. The security mechanisms in WiMedia control the security operation of devices by setting appropriate security modes [5]. They allow devices to authenticate each other, to derive PTKs, and to establish secure relationships [5]. They also enable devices to solicit or distribute GTKs within established secure relationships [5].

WiMax supports two encryption standards: data encryption standard 3 (DES3) and advanced encryption standard (AES). Thus, different access technologies use different types of security.

Charging or billing is certainly of paramount importance to both the operator and the mobile user. Any simplification in the bill would be most welcome by the mobile user. Moreover, the operator may also offer an overall cheaper plan to the subscriber using the heterogeneous networks due to new revenues generated in the new services introduced across the access technologies. Service discovery mechanisms are also needed for a mobile device to discover new services and networks within its region. A mobile device can find more about the available access technologies and their services in its vicinity. These will enable it to connect to the available best connection (ABC).

Effective routing protocols in the WPANs are also needed to support all possible services and their QoS constraints. Enabling services with QoS constraints to be met in multihop WPANs is certainly an important technical challenge.

Many challenging technical issues need to be solved before the convergence of networks envisaged in this section can be realized. However, once it is achieved, mobile users can enjoy the fruits of this labor.

## 6. SUMMARY

3GPP/WLAN interworking between cellular technologies and WLANs, IEEE 802.11u interworking of IEEE 802.11 WLANs with external networks, and IEEE 802.21 media-independent handoff for heterogeneous access technologies such as IEEE 802.3, IEEE 802.11, IEEE 802.16, 3GPP cellular networks, and 3GPP2 cellular networks are certainly the specifications and standards to look for in the convergence of networks today.

The future envisaged for cellular/ WiMax/WLAN/WPAN interworking in a convergence of networks, and some issues relating to the interworkings of various access technologies, are discussed in this chapter. Once these interworkings between technologies are achieved, together with new rate adaptive services across them, users can enjoy truly seamless and user-transparent connectivity based on the best connection available.

## REFERENCES

[1] *** (2007) *"3rd Generation Partnership Project: technical specification group services and system aspects; feasibility study on 3GPP system to wireless local area network (WLAN) internetworking,* (Release 7)", 3GPP TR 22.934 V7.0.0.

[2] F. Cacace and L. Vollero. (2006) *"Managing mobility and adaptation in upcoming 82.21-enabled devices,"* WMASH 2006, Los Angeles, CA, Sept. 29.

[3] A. Dutta, S. Das, D. Famolari, Y. Ohba, K. Taniuchi, V. Fajardi, R. M. Lopez, T. Kodama, and H. Schulzrinne, (2007) *"Seamless proactive handoff across heterogeneous access networks",* Wireless Personal Commun., vol. 43, pp. 837–855.

[4] A. de la Olivia, T. Melia, A. Vidal, C. J. Bernardos, I. Soto, and A. Banchs, (2007) *"A case study: IEEE 802.21 enabled mobile terminals for optimized WLAN/3G handovers",* Mobile Comput. Commun. Rev., vol. 11, no. 2, Apr.

[5]*** (2005) *"High rate ultra wideband PHY and MAC standard",* Standard ECMA-368, ECMA International, Geneva, Dec. 2005.

[6] E. Stevens-Navarros, C. Sun, and V. W. S. Wong. (2007) *"A survey of analytical modeling for cellular/ WLAN interworking",* in Emerging Technologies in Wireless LANs: Theory, Design and Deployment, Cambridge University Press, New York.

[7] E. Stevens-Navarros and V. W. S. Wong (2007) *"Resource sharing in an integrated wireless cellular/WLAN system",* Canadian Conference on Electrical and Computer Engineering 2007, Vancouver, British Columbia, Canada, Apr.

[8] W. Song, H. Jiang, and W. Zhuang. (2007) *"Performance analysis of the WLAN-first scheme in cellular/ WLAN interworking",* IEEE Trans. Wireless Com0mun., vol. 6, no. 5, pp. 1932–1943, May 2007.

[9] W. Song and W. Zhuang, *"Multi-service load sharing for resource management in the cellular/WLAN integrated network,"* IEEE Trans. Wireless Commun.