

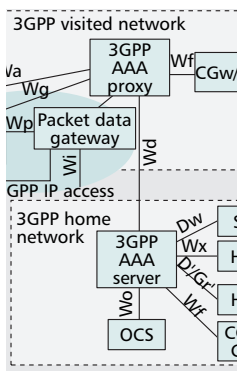
# SERVICES IN INTERWORKING 3G AND WLAN ENVIRONMENTS

DIMITRIOS I. AXIOTIS, TAREQ AL-GIZAWI, KONSTANTINOS PEPPAS, AND EMMANUEL N. PROTONOTARIOS, NATIONAL TECHNICAL UNIVERSITY OF ATHENS, GREECE

FOTIS I. LAZARAKIS, NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS," GREECE

CONSTANTINOS PAPADIAS, BELL LABS, LUCENT TECHNOLOGIES, UNITED STATES

PANOS I. PHILIPPOPOULOS, TEMAGON S.A, GREECE



The interworking of WLANs and Third Generation Mobile Networks is a major step toward a new generation of wireless networks, where other radio technologies will be also integrated.

## ABSTRACT

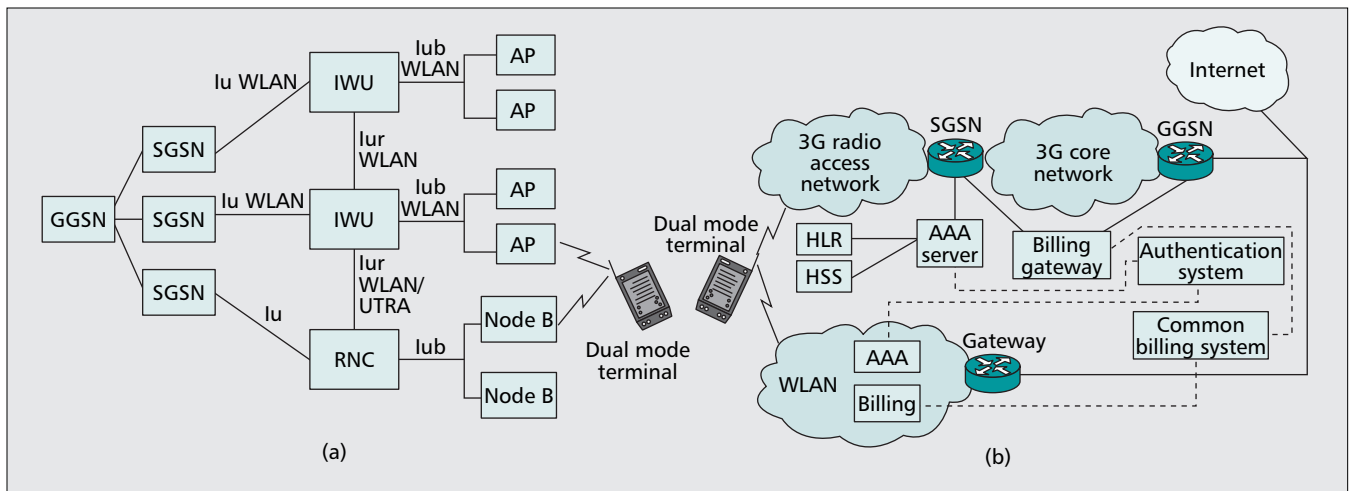
Interworking WLANs and 3G mobile networks are expected to provide ubiquitous wireless communications at high data rates and a large variety of services with variable bandwidth and QoS requirements, across a wide range of propagation environments and mobility conditions, using dual mode terminals. The interworking of the two networks is a major step toward a new generation of wireless networks in which other radio technologies will also be integrated. In this article we present possible architectures that enable the interworking of 3G and WLAN networks. We then address the capabilities of various terminal types and describe future services in the interworking environment. Finally, we present market forecasts on terminal and service demand growth.

## INTRODUCTION

Third-generation (3G) networks will provide voice and data services with ensured wide coverage. The ever increasing user demand for high data rates (triggered by new applications such as videophone or video streaming) can be met by implementing hierarchical layers of macro-, micro-, and picocells, each using different carriers. Micro and pico cells can provide extra capacity at the expense of costly base stations in small coverage areas. Techniques such as cell sectorization and multiple-input multiple-output (MIMO) can be further employed in order to maximize capacity. On the other hand, wireless LANs (WLANs) provide increased capacity (up to 54 Mb/s for IEEE 802.11a,g and HIPERLAN/2) with a radio coverage of 100 or 30 m radius in outdoor and indoor environments, respectively. Sectorization and MIMO techniques are also standard friendly for WLANs. The main advantage of WLANs is the low cost of deployment: the access points (APs) cost only a small fraction of what expensive 3G base sta-

tions — referred as Node Bs — do, and although a significantly larger number of APs must be utilized in order to cover the same area, the total cost is still smaller than the cost of deploying a 3G network. Of course, this is valid only for small coverage areas such as hotspots usually covered by a limited number of Node Bs. It would not be cost-efficient to cover an urban area by WLAN, since for such a large number of APs other parameters such as the cost of backhaul links also become significant. Under some circumstances, some APs may be collocated with Node Bs, so no extra site leasing cost is required. It should be also noted that WLANs operate in the unlicensed spectrum, while the 3G operators participated in auctions in order to lease their frequency bands. The trade-off is that the use of unlicensed spectrum generates the problem of uncoordinated interference, which in turn reduces the range of radio access. Note that for this reason mobile broadband wireless access (MBWA) systems, IEEE 802.20, will operate in licensed bands below 3.5 GHz.

Their small radio coverage capability dictates that WLANs cannot provide the wide coverage benefits of 3G. WLANs can only be deployed in a cost-efficient manner in areas where increased user demand is expected (i.e., hotspots like airports, city centers, conference sites, cafés, hotels, and university campuses). Considering the main features of 3G and WLANs as separate networks, we can summarize their basic differences: 3G networks will be broadly deployed, thus always available for use through small mobile terminals with no limits on user speed/mobility, while WLANs are characterized by location-dependent availability, limited user speed/mobility, and bigger terminals (laptops, PDAs). Furthermore, 3G provides both voice and data (up to 2 Mb/s) with content reduced due to screen size at a medium/high cost per byte, while WLANs provide access to data services (at even higher data rates) with full (or nearly full) representation of the content at a low cost per byte.



■ **Figure 1.** a) Tight and b) loose interworking architecture of 3G/WLAN networks.

All the attributes discussed above lead to the conclusion that the two networks have complementary advantages and disadvantages (i.e. for an attribute where one network has an advantage, the other has a disadvantage). Thus, the idea of integration of the two networks to unify the advantages of the two systems and at the same time minimize the disadvantages arises as a great market opportunity.

It is clear that integration of these two heterogeneous wireless networks would be doubtful if there was no possibility of manufacturing dual mode terminals capable of attaching to both radio interfaces. Such terminals are already available for the current generation of wireless systems. PDAs incorporating IEEE 802.11b and Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS) are already available. Their cost is rational, since most manufacturers give the flexibility of buying add-on cards (with either radio interface) to their customers. This trend will eventually lead to a new type of dual mode terminal that will be the joint evolution of cellular phones and PDAs. Furthermore, if we take into account that 3G and WLANs share mutual complementing advantages and disadvantages, it is obvious that we have a key driving force for their integration. Indeed, Japan's NTT DoCoMo announced the development of the N900iL, a dual network 3G Freedom of Mobile Multimedia Access (FOMA) handset that runs on both FOMA and IEEE 802.11b [1]. The handset, scheduled to be marketed in fall 2004, has been specifically designed to support the integration of two-network operation. Note that WLANs were first perceived as a threat by 2G operators, due to their capability of providing voice over IP. After realizing the market potential of the interworking option, however, most parties favor this possibility.

## INTERWORKING ARCHITECTURES OF 3G AND WLAN NETWORKS

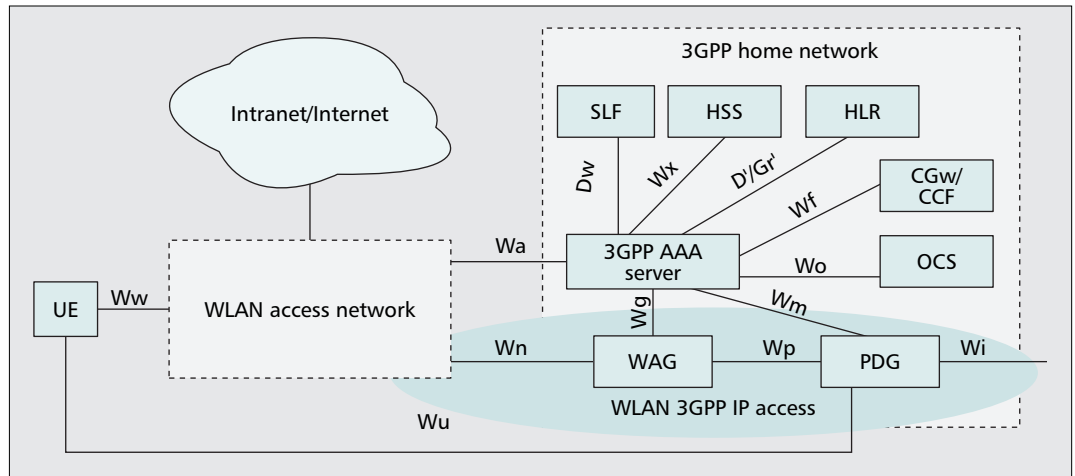
There are two fundamentally different architectures that can enable the interworking of the two networks: loose and tight interworking (also

referred as loose/tight coupling in [2]). The tight interworking approach has as a prerequisite that the WLAN is an access technology within the 3G serving GPRS support node (SGSN). On the other hand, the loose interworking approach does not necessitate that the WLAN conform to the complicated 3G access/core network interfaces. Handover from WLANs to 3G and vice versa shall be supported. Some of the WLAN supported user services may not be supportable in 3G networks and/or may not be robust enough for the handover requirements. Services that will suffer from the latter are typically time stringent, as for the former these may be services/applications that require an amount of capacity that is not supported. In cases where the service/application cannot be supported due to a change of access network, the user should be notified of the forthcoming termination. In cases where the service/application may be supported but with degradation of the provided quality, the user may be controlled through a subscription. The subscription may define the level of mobility between WLANs and 3G that the user requests on certain services/applications with an agreed quality that is applicable to provide in the serving access network. In any circumstances the user should be notified of any possible degradation or improvement of the provided quality of service (QoS) due to the change of access network. In this section we describe the aforementioned interworking architectures as well as the current solution adopted by the 3G Partnership Project (3GPP) [3, 4].

In Fig. 1a we present the tight interworking architecture. The WLAN network is connected to the 3G core network in the same manner as other 3G radio access technologies, such as Universal Mobile Telecommunications System (UMTS) terrestrial radio access (UTRA): using the Iu WLAN interface, which is quite similar to the Iu interface. In this way, the mechanisms for mobility, QoS, and security of the 3G core network can be reused [2]. WLAN APs are connected to interworking units (IWUs) through the Iub WLAN interface. The gateway GPRS support node (GGSN) connects the network to the Internet.

Loose interworking (Fig. 1b) is defined as the utilization of WLAN as an access network com-

Within 3GPP, ongoing standardization work is addressing the feasibility of interworking and interworking architectures of 3G and WLAN networks. More specifically, the loose interworking architecture has been adopted for Release 6, since it provides greater flexibility and scalability.



■ **Figure 2.** Non-roaming 3GPP reference architecture.

plementary to 3G access networks, using subscriber databases but without any user plane Iu type interface (i.e., avoiding the SGSN and GGSN). The operators will still be able to utilize the same subscriber database for 3G and WLAN clients, allowing centralized billing and maintenance for different access technologies. More specifically, only IP services are supported across the access network, while authentication, authorization, and accounting (AAA) functions directly access core network control functions.

Within 3GPP, ongoing standardization work is addressing the feasibility of interworking, and interworking architectures of 3G and WLAN networks [3, 4]. More specifically, the loose interworking architecture has been adopted for Release 6, since it provides greater flexibility and scalability; with this solution the WLAN does not need to conform to complicated Iu type interfaces, while at the same time in many cases WLAN and 3G operators will not be the same entity, an option favored by the tight interworking architecture. In [3] six interworking scenarios that represent steps in interworking of WLAN and 3GPP networks have been identified. The scenarios are described by an incremental set of service and operational features:

- Common billing and customer care
- 3GPP system-based access control and charging (IP access over WLAN for 3GPP subscribers)
- Access to 3GPP system packet-switched (PS)-based services, such as short message service (SMS), Wireless Access Protocol (WAP), and multimedia message service (MMS), from an interworking WLAN
- Service continuity (nontransparent service maintenance across WLAN and 3G)
- Seamless service provision (transparent service maintenance across WLAN and 3G)
- Access to 3GPP circuit-switched (CS) services (possibly will not be addressed)

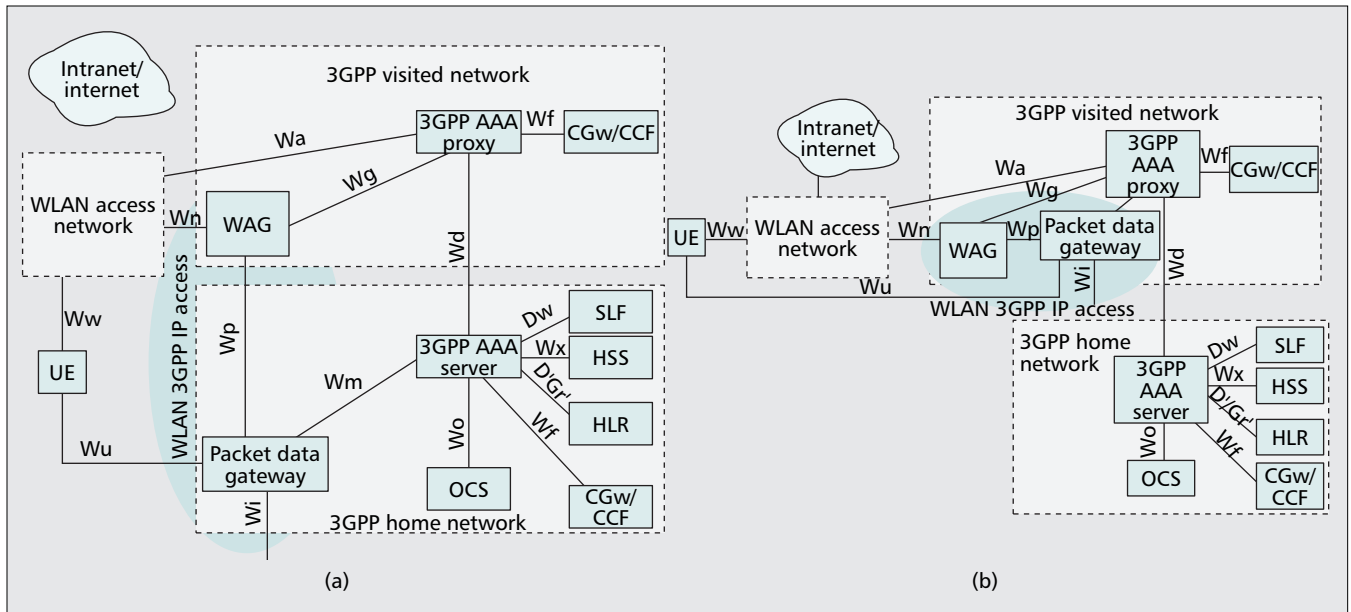
The architectures described in [4] include non-roaming (Fig. 2) and roaming (Fig. 3) interworking reference architectures. There exist two roaming architectures with respect to whether the 3GPP PS services are provided via the home (Fig. 3a) or visited 3G network (Fig. 3b). Note that the shaded areas refer to WLAN 3GPP IP access functionali-

ty. The Wn interface connects the WLAN access network and WLAN access gateway (WAG). Wa is the reference point between the WLAN access network and a 3GPP AAA server/proxy (charging and control signaling). The Wi is the interface between the packet data gateway (PDG) and an external IP network, and Wp the interface between the WAG and the PDG. Furthermore, Wu is the reference point between WLAN user equipment (UE) and a PDG, and Wd the reference point between a 3GPP AAA proxy and a 3GPP AAA server. The other reference points (Wx, D'/Gr', Wf, Wo, Wm, Dw, and Wg) and the associated protocols crossing these points, are responsible for the connection of Home Subscriber Server (HSS), Home Location Register (HLR), Charging Gateway/Charging Collection Function (CGw/CCF), Online Charging System (OCS), PDG, Subscription Locator Function (SLF) and WAG to the AAA server, respectively.

## A DESCRIPTION OF TERMINAL CAPABILITIES

The 3G terminals demonstrated by many manufacturers have similar features with PDAs. As we already mentioned, PDAs can also be equipped with 3G and WLAN modules. It is foreseeable that in the near future the two handheld types will evolve into a single terminal type combining features of both categories. Pure 3G terminals will likely not become extinct since some users would still want a simple, small and cheap device for their basic needs. From a network point of view all interoperating terminal types expected in an interworking WLAN/3G network are:

- A multimode terminal (i.e., one terminal or one module such as a PC card with many different radio interfaces)
- Separated modules with different radio interfaces
  - The modules are used in a single terminal. A driver selection function between active modes in a terminal can be used to handle modules with different radio interfaces.
  - The modules can be used in separated terminals (e.g., a 3G cell phone with no WLAN capability and a WLAN enabled laptop). These two terminals can communicate over a third interface (e.g., Bluetooth), which can



**Figure 3.** Roaming reference architecture — 3GPP PS-based services provided via the a) 3GPP home network and b) 3GPP visited network.

enable the interworking between WLAN and 3G networks [2].

All terminals are expected to have color displays, while 18-bit color (262,144 colors) is already available, and 24-bit color may be achievable through interpolations. The screen size selection is a function of three main parameters: terminal size, power dissipation, and operating system (OS) limitations. Taking as a reference the current generation of PDAs, Palm OS Garnet (an enhanced version of OS 5) supports resolutions up to  $320 \times 320$ , QVGA ( $240 \times 320$ ), and HVGA ( $320 \times 480$ ) [5]. The rival OS, PocketPc (formerly called Windows CE, Microsoft) also supports QVGA [6]. If the screen is built up from LCDs, the decision to employ a large screen includes a trade-off between better resolution and higher power consumption. A solution to this dead end are displays based on organic LEDs, currently under development. The same trade-off appears in the choice of CPU: 400 MHz or even more powerful processors are readily available, but power consumption is an increasing function of the frequency/computational power. The internal memory will range from 16 to 64 Mbytes. Memory sticks/flash memory cards already run over 4 Gbytes, so storage space will be the least user-limiting factor of the terminal.

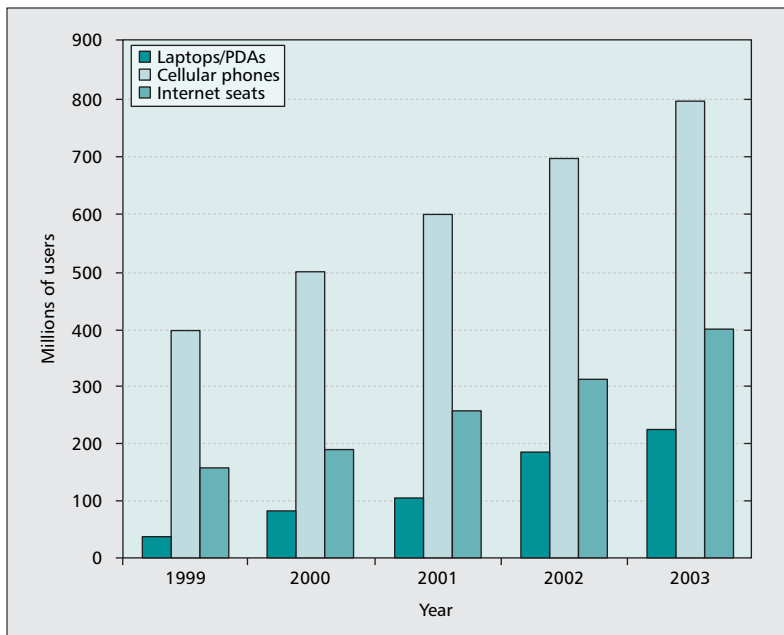
## SERVICES

Before we describe the services in the interworking WLAN/3G network, it is important to define some restrictions imposed due to three main parameters: terminal capabilities, user mobility, and system interoperability issues.

The terminal capabilities directly influence the types of services that will be used. Cheap terminals may not be able to support all 3G modes (i.e., high data rates or high-speed downlink/uplink packet access [HSDPA-HSUPA]). Thus, some terminals will not be able to support high-data-rate applications. Furthermore, the screen size dictates that Web browsing cannot be expe-

rienced the same way as in desktop PCs or laptops: users will have to scroll from left to right and from top down in order to view the full page, which is not convenient or enjoyable. In addition, experience with the current generation of PDAs shows that the terminals cannot handle multiple Web browser windows or popup windows. As the screen size cannot be increased, it is obvious that Web page developers should start considering providing small-screen-friendly versions of Web pages. When a user requests a Web page, the server can detect the OS of the terminal or other features (e.g., screen size) and automatically redirect the user to a resolution optimized version of the Web page. The limited computational power of the terminal CPU can also be challenging for some applications: MPEG-4 video streaming, for example, requires high computational power (soft coding/decoding) and may only be available to terminals implementing hardware coders/decoders.

User mobility in the interworking network will also influence the available services. Since the WLAN will only be available in hotspots, users running high-data-rate services and heading out of hotspot coverage may experience a degradation of data rate since their session will be handed over to 3G. If the QoS attributes of their current session cannot be satisfied by the 3G network, they will be notified about an imminent service termination. It could also be possible for the user to maintain the same connection but at a lower QoS rather than service termination, depending on service type. Thus, interoperability issues such as system capacity and load balancing must be taken into account. A user may request a certain service; the request will be served by the available network not only in terms of coverage, but also system throughput and load balancing (i.e., applications with inherent high guaranteed bit rates should be directed to the network that can efficiently serve them at the given time period).



■ **Figure 4.** The growth of cellular phones with respect to laptops/PDAs and Internet seats.

## SERVICE CATEGORIES

The services in the interworking WLAN/3G network can be classified in several categories: person-to-person communications, entertainment, mobile transactions, mobile information, and business solutions. Web browsing is an application associated with almost all of the above categories. For each category various applications are described and characterized into QoS classes (conversational, streaming, background, and interactive) [7].

**Person-to-Person Communications** — The need to communicate with other people is met with one-to-one and one-to-many applications such as voice, videophone, MMS, text messaging (SMS), messengers (e.g., ICQ), and mobile emailing. There will be easy market adoption for person-to-person communications as they are familiar service concepts to users. Videophone is expected to be the application that will raise the interest of typical users and eventually lead them to make the transition from 2G to 3G. It would be really convenient, especially for handheld devices, if one software program could handle all types of services. From a QoS point of view, voice and videophone are real-time services (conversational class) and stringent to time delay latencies, while the other services adhere to the best effort model (background class).

**Mobile Entertainment** — Mobile entertainment is another service category that is expected to be popular with most users while at the same time ensuring revenues for operators. Services can be of several types such as:

**On-demand video/audio streaming (streaming class)** — The user may request music, a radio program, or the highlights of a football game, for example. The content starts “playing” while it is downloading. This service can be free

or charged, depending on the origin of the media, royalty fees, and so on.

**On-demand background class video/audio (background class)** — This type of service involves the download of audio/video files that can be played afterwards. Since the user may store files (e.g., MP3) in the terminal, royalty fees to the media proprietor will be paid.

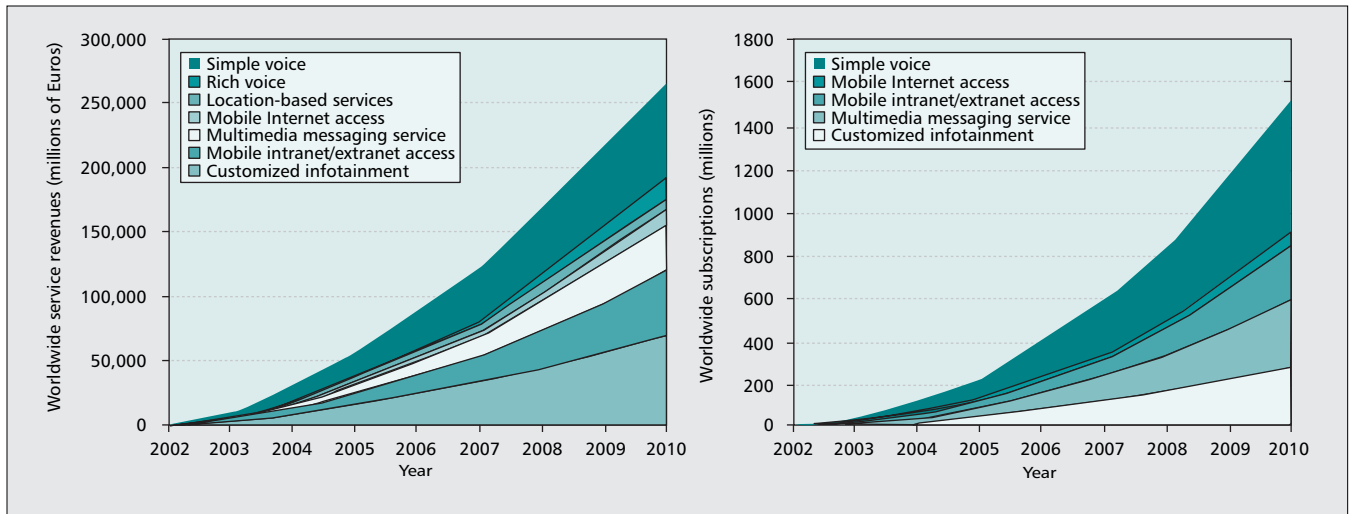
**Games (background class/interactive for online games)** — Java-enabled Web browsers can be used for online games. Recently a popular game console (Nintendo’s Gameboy) emulator for PDAs has been released and is freely distributed. This trend is expected to boom in future terminals, with game ROMs downloaded for a small fee.

**Chat (interactive/background class)** — Clients such as Internet relay chat (IRC) or mobile chat rooms organized in interest categories will be available.

**E-books (background class)** optimized for reading through small displays can be downloaded/purchased.

**Mobile Information** — News, financial, sports, weather, and traffic information belong to this category. This service category can be provided through an Internet Web browser (interactive class), and the users are charged only for network access. An alternate option would be to implement such information as “push” services (background class) to which users can subscribe based on need and interest. The value of these services is increased if the user can be kept informed and up to date. For instance, the user can receive information about the prices of shares and the latest news about companies in which he/she has intentions of investing. Pull services, like directory services, will be enhanced with user requests based on his/her location. For example, a traveler can request information via his/her terminal for the nearest gas station when he/she is driving in an unfamiliar district or country. The directory can then send back the addresses and location maps of the two nearest stations. Personalized messages can be sent to the user’s terminal rather than distributed via mass communications. For instance, a user who is looking to buy an apartment can get updated information from the operator on available apartments in the district of his/her choice. The user can then make an offer to an agent or landlord, or simply discard, depending on his/her interest. This is a more direct way of getting relevant and updated information than through the newspapers or the Internet, which is dependent on the user’s active scanning and selection.

**Location-Based Services** — An important feature of many applications operators and vendors are exploring is location-based service delivery. These services (interactive class) can include location-aware information and community services. The main driver for mobile services is making the data service relevant to users while they are mobile. A lot of content delivery can be based on geographic location (i.e., advertising); the gas station example given in the mobile information section fits in the location-based services category as well. Operators can earn adver-



■ **Figure 5.** *Worldwide revenues and subscriptions per application in 3G networks for the years 2002-2010.*

tising revenue because they know the user's location, personal profile information, or segmented channel. Push advertisements can be subscription-based so that the mobile user can indicate to the operator the information he/she is interested in (i.e., his/her personal profile). The operator can thus send location-relevant messages based on user search or advertising. If the user agrees to a transaction, the operator can then be entitled to a commission of the value, say 5 or 10 percent.

**Mobile Transactions** — Most applications of mobile transactions include mobile finance (banking, brokering, payment, cash), mobile shopping (retailing, ticketing, auctions, reservations, postcards), mobile advertising, mobile entertainment (gaming, music, video, betting), telematics, and mobile user care. All transactions adhere to the interactive class. Mobile commerce is any transaction with a monetary value conducted over a mobile network, so mobile terminals become "electronic wallets." The user can, for example, buy goods and have the value debited from his/her electronic wallet as a micropayment transaction. For a larger purchase, the mobile terminal can be used to initiate a credit card transaction with a PIN code authorization, as the mobile operator already has the credit card details. Security features built into the terminals and network will make this a highly secure purchasing method. Of course, transactions can always take place through secure HTTP Web browsing.

**Business Solutions** — This category of services can be characterized as background or interactive depending on the application. Corporate-type services offer business users up-to-the-minute information, data transfer, and secure connections to the Internet and corporate LAN. Virtual private networks (VPNs) can be securely developed and provide access to customer relationship management to satisfy the communications and information needs of knowledge workers. Corporations are willing to pay a premium while their workers are on the go, so this type of service will give significant revenues to operators.

## MARKET FORECASTS

The key driving force for the interworking of 3G and WLANs, apart from the indisputable benefits in terms of system performance, is the market potential of this scenario. Both hardware manufacturers and system operators would benefit from such a possibility, by boosting their sales and subscriber revenues, respectively. In this section we present market forecasts for the number of terminals, expected revenues/number of subscriptions per service, and number of WLAN hotspots.

In Fig. 4 we present the increase in cellular phones, PDAs/laptops, and Internet seats recorded worldwide in the period 1999–2003 [8, 9]. PDAs seem to follow the increase rate of mobile phones. In the near future, however, the increase rate of cellular phones will minimize as cellular telephony has reached very high penetration percentages (especially in Europe), while PDAs will continue to achieve high increase rates. The penetration of terminals/networks in developing countries (e.g., China, India) will have a great impact on future terminal increase rates. Figure 4 gives us an idea of the market potential of dual mode terminals in interworking 3G/WLAN networks.

Figure 5 presents the worldwide revenues per application and worldwide subscriptions per application in 3G networks for the years 2002–2010 [10]. After a certain point revenues from data services will become comparable to voice and rich calls (videophone). The metrics presented concern 3G terminals, but are also indicative for handheld dual mode terminals.

In Table 1 we depict the forecast increase in the number of WLAN hotspots in cafés/restaurants and airports [9]. It is obvious that a large number of airports will be able to provide WLAN access to passengers. On the other hand, the increase in small WLANs (cafés) is enormous. An extensive set of forecasts for all hotspot environments can be found in [9]. The forecast growth of WLANs is counterbalanced, however, by an uncertain revenue opportunity since the cost per byte will be significantly smaller than that for 3G networks [9].

Forecasts show that each network has very

Number of hotspots in cafés and restaurants							
Year	2000	2001	2002	2003	2004	2005	2006
US	900	2700	7000	14,000	22,000	30,000	40,000
Europe	60	180	600	2700	6000	11,000	18,000
Asia	40	120	400	1300	3000	5000	8000
<b>Total</b>	<b>1000</b>	<b>3000</b>	<b>8000</b>	<b>18,000</b>	<b>31,000</b>	<b>46,000</b>	<b>66,000</b>

Number of hotspots in airports							
Year	2000	2001	2002	2003	2004	2005	2006
US	100	150	220	300	375	445	510
Europe	30	50	75	105	160	210	230
Asia	30	45	65	95	125	160	200
<b>Total</b>	<b>160</b>	<b>245</b>	<b>360</b>	<b>500</b>	<b>660</b>	<b>835</b>	<b>1020</b>

**Table 1.** Growth of WLAN hotspots in cafés/restaurants and airports for the period 2000–2006.

promising potential. The interworking of the two networks (possible architectures are discussed in this article) and dual mode terminals will maximize user satisfaction in terms of service availability and high data rates at rational cost, and further boost the penetration of the two networks. Apart from technological reasons, the two networks may have to interwork for financial reasons as well: the profitability of WLAN services is still an open question; when coupled with the wide coverage of 3G they could become more attractive from a profit point of view.

## CONCLUSIONS

The interworking of 3G and WLANs presents a great technological advancement opportunity in terms of system performance and at the same time introduces great market potential. In this article we present system interworking architecture types and describe the interoperability mechanism. We focus on network, terminal, and user-oriented parameters that will shape future applications. The services that will be available in interworking WLAN/3G networks are classified in categories; the corresponding QoS classes are also indicated. Market forecasts on the number of terminals, hotspots, and revenues per service type are analyzed. It is apparent that the financial benefits that could be achieved by the interworking of the two networks constitute an additional reason for adopting this option.

## ACKNOWLEDGMENT

Part of this work was performed in the context of IST-FITNESS (Fourth Generation Intelligent Transparent Networks Enhanced through Space-Time Systems).

## REFERENCES

- [1] [http://www.nttdocomo.com/presscenter/pressreleases/press/pressrelease.html?param\[no\]=470](http://www.nttdocomo.com/presscenter/pressreleases/press/pressrelease.html?param[no]=470)
- [2] ETSI TR 101 957, "Broadband Radio Access Networks (BRAN), HIPERLAN Type 2: Requirements and Architectures for Interworking between HIPERLAN/2 and 3rd Generation Cellular Systems."

- [3] 3GPP TR 22.934 V6.2.0 (2003-09), "Feasibility Study on 3GPP System to WLAN Interworking."
- [4] 3GPP TS 23.234 V6.1.0 (2004-06), "3GPP System to WLAN Interworking; System Description."
- [5] <http://www.palmsource.com/palmsos/garnet.html>
- [6] <http://www.microsoft.com/windowsmobile/pocketpc/ppc/default.mspx>
- [7] 3GPP TS 23.107 V6.1.0 (2004-03), "QoS Concept and Architecture."
- [8] UMTS Forum Report 10, "The Future Mobile Market," Oct. 2000, <http://www.umts-forum.org>
- [9] IST-FITNESS D4.1 "System-Level Simulation Methodology," <http://www.telecom.ntua.gr/fitness>
- [10] UMTS Forum Rep. 17, "The UMTS Third Generation Market Study Update," Aug. 2001, <http://www.umts-forum.org>

## BIOGRAPHIES

DIMITRIOS I. AXIOTIS [M] ([jaxiot@telecom.ntua.gr](mailto:jaxiot@telecom.ntua.gr)) received his Diploma (1999) and Ph.D. degree in 3G mobile communications (2004), both from the Department of Electrical and Computer Engineering, National Technical University of Athens (NTUA), Greece. He is currently a research associate in the Telecommunications Laboratory at NTUA, participating in FP5/FP6 research projects. His research interests involve HAPS-UMTS and interoperating HSDPA/WLAN networks enhanced with MIMO techniques.

TAREQ AL-GIZAWI ([tarek@telecom.ntua.gr](mailto:tarek@telecom.ntua.gr)) is a Ph.D. candidate at the Institute of Computer and Communication Science at NTUA. His main research area is 4G mobile communication systems; specifically mechanisms and algorithms that enhance seamless interworking between heterogeneous networks in the 4G environment. He has taken part for two years (2001–2003) in the European IST-FITNESS project. He is expected to obtain his Ph.D. degree by September 2004.

KONSTANTINOS PEPPAS ([peppas@telecom.ntua.gr](mailto:peppas@telecom.ntua.gr)) obtained his diploma in electrical and computer engineering from NTUA in 1997 and his Ph.D. degree in wireless communications from the same department in 2004. His current research interests include wireless and personal communication networks, system level analysis and design, signal processing, and applied mathematics.

EMMANUEL N. PROTONOTARIOS ([protonot@cs.ntua.gr](mailto:protonot@cs.ntua.gr)) received a degree in mechanical and electrical engineering from NTUA (1963) and a Ph.D. degree in electrical engineering from Columbia University (1966). He has been a professor in the Department of Electrical and Computer Engineering, NTUA since 1973. From 1966 to 1968 he worked at Bell Laboratories, Holmdel, New Jersey, and from 1968 to 1973 he was an assistant/associate professor of electrical engineering at Columbia.

FOTIS I. LAZARAKIS ([flaz@iit.demokritos.gr](mailto:flaz@iit.demokritos.gr)) received a diploma in physics (1990) from Aristotle University of Thessaloniki, Greece, and a Ph.D. degree in mobile communications (1997) from National and Kapodistrian University of Athens. From 1999 to 2002 he was with the Telecommunications Laboratory at NTUA and then with the National Center for Scientific Research "Demokritos," Institute of Informatics and Telecommunications, as a researcher. His research interests include 3G and 4G systems, WLANs, and smart antenna systems. He has authored more than 20 journal and conference papers.

CONSTANTINOS PAPADIAS [SM] ([papadias@lucent.com](mailto:papadias@lucent.com)) received a diploma in electrical engineering from NTUA in 1991 and a Ph.D. degree in signal processing from l'Ecole Nationale Supérieure des Télécommunications (ENST), Paris, France, in 1995. Since 1997 he has been with Lucent Technologies' Wireless Research Lab, where he is currently technical manager. He is a member of the Technical Chamber of Greece.

PANOS PHILIPPOPOULOS [M] ([pfilip@ieee.org](mailto:pfilip@ieee.org)), head of EU R&D at TEMAGON, consulting branch of Greek ex-incumbent operator OTE, received his diploma in electrical and computer engineering in 1994 and his Ph.D. in mobile/personal telecommunications in 1999, both from NTUA. He has participated in several European programs (RACE, ACTS, IST-FP5/6). His research interests include satellite/terrestrial service integration, service discovery/provision, and business modeling for 4G pervasive environments. He is a member of the Technical Chamber of Greece