

In *The Broadband Explosion: Leading Thinkers on the Promise of a Truly Interactive World*, edited by R. D. Austin and S. P. Bradley, Harvard Business School Press, 2005, pp. 225-239.

Wireless Local Area Networks: Why Integration Is Inevitable

H. T. Kung

It is increasingly evident that the growth of wireless local access networks (WLANs) based on 802.11x standards like Wi-Fi will soon be massive and widespread. Enterprises and end users are enthusiastically committing resources into WLAN deployment to benefit from the technology. This phenomenon resembles the widespread deployment of private wireline Ethernets in the 1990s.

The rapid deployment of WLANs in homes, offices, and public areas, and the relatively inexpensive bandwidth of WLANs are prompting many observers to ask how the emergence of WLANs will affect the telecom industry. Some see WLANs as direct competitors to the telecommunications high-bandwidth third-generation (3G) technologies; others view the two phenomena as complementary.¹ Some perceive WLANs as providing mainly mobile data services, while others expect WLANs to generate a new wave of opportunities in voice services.²

This chapter will examine the fundamental reasons why the impact of WLANs on telecommunications will be profound, even though it is too early to predict the specific implications for particular industrial sectors or for the definitions of standards. We will offer an analytic roadmap, with analysis and

application scenarios, of how WLANs could be integrated into telecommunications devices, systems, and services. We view this integration process as only the latest instance of the merging of existing communication and data networks, with WLAN-enabled cellular handsets as a convergence point. Such handsets can be viewed as an initial focal point in the integration of WLAN in telecoms, in the sense that they are certain to bootstrap other integration efforts.

Usage Examples of WLANs in Telecoms

We expect many users to be eager to use cellular handsets for WLAN access. The ability to access WLANs with handsets, when in a WLAN environment, would represent a welcome convenience for those who always carry cellular handsets and regularly use WLANs in their homes and offices via other devices. These users can now use some handsets to download and upload multimedia content and messages, conduct video conferencing, and play interactive cellphone games over high-bandwidth, inexpensive, always-connected WLAN connections. Today, however, they must tolerate the inconvenience of switching to a PDA, laptop, or desktop with a WLAN interface before they can access a WLAN.

Early versions of dual-mode handsets that support both cellular and WLAN connections are already undergoing market trials.³ Other models are expected to become available shortly. Consider, for example, the various smartphone handsets currently on the market, which implement PDA-like functionality with cell-phone form factors. It will be relatively straightforward to enable these handsets to support WLANs, since many PDAs already have built-in or add-on WLAN interfaces and protocol stacks to run applications such as Web

browsing and instant messaging. Indeed, a recent exhibition demonstrated a number of WLAN applications on an existing smartphone handset by using a WLAN card inserted into the SD card slot.⁴

Another possible scenario is the use of WLANs by fixed-wire phone operators to provide local loops and to access Voice over IP (VoIP) services from data links such as DSL/cable lines, which would represent a last-mile alternative for operators and a convenience for their subscribers. These subscribers can now use WLANs to access PBX systems or phone lines with the WLAN-enabled portable phones or the dual-mode cellular phone handsets described above. In WLAN-enabled homes and offices, cellular handset users can thus leverage the convenient features of handsets (phone books, caller lists) while consuming higher-quality and possibly also cheaper noncellular phone services. Fixed-wire phone operators may very well bundle these added services with conventional DSL and cable modem offerings.

Integration of WLANs in Telecoms

From a technological perspective, integration means that cellular handsets have the dual capability of using both WLANs and telephone networks. We will call these dual-mode handsets *WLAN-enabled handsets*.

Integration also means that WLANs and cellular networks are able to interoperate at certain network layers. There are two approaches to integration, often called *tightly coupled* and *loosely coupled* internetworking.⁵ In the tightly coupled approach, integration is implemented at a network layer below the IP layer. With integration of this kind, the WLAN will appear to the cellular core

network as another cellular-access network. As a result, seamless handoff between cellular and WLAN networks can be expected. Further standardization and development efforts are needed however, to realize this capability, and deployment of tightly coupled internetworking is thus likely to be years away.

The other approach, loose coupling, implements integration at the IP layer. Using IP protocols, the cellular core network can use existing authentication, authorization, and accounting (AAA) systems, such as the home-location register (HLR) or home-subscriber server (HSS), to support WLAN services and applications. That is, a terminal on a WLAN can send and receive AAA messages to and from the operator's AAA gateway over an IP network. Loose coupling is readily implementable using existing protocol standards, and it can already be useful in providing AAA and other services for WLANs. For purposes of this chapter we will assume that only loose coupling is implemented.

There are also less integrated methods, such as using a GPRS/WLAN PC card in a PC or PDA to allow it to use both GPRS and WLAN networks. Hybrid approaches of this kind can be useful in some applications, such as providing both WLAN and dial-up support for travelers. But because these solutions still require users to carry PDAs or PCs, we expect them to have less impact on telecommunications than integrated solutions.

For a more detailed discussion on integration methods, refer to the six coupling scenarios defined by 3GPP each with an increasing level of integration for the interworking¹⁴.

The Challenges and Opportunities of Integration

Independently Developed WLANs

In loosely coupled integration, the telephone network will integrate its core with independently developed WLANs rather than using traditional access networks designed together with the core. Sometimes the core will even be integrated with WLANs which are independently deployed and managed by other operators. In this case, loosely coupled integration is a matter of integrating *private* networks (WLANs) with *public* networks (phone networks). This degree of integration of heterogeneous networks appears to be unprecedented in the telecommunications industry. Needless to say, it must be feasible not only technically but also as a business proposition.

Public WLANs

The business viability of public WLAN hotspots, such as airports, conference centers, exhibition halls, railway stations, and stores, is subject to considerable debate. These hotspots and the business opportunities they embody have attracted substantial attention from telecommunications operators, but the hotspot business has not proven as profitable as initially expected, except in places like busy airports where there are many business travelers. This pattern is understandable, given that most WLAN deployment so far is concentrated in homes and enterprises where the WLAN interface is available to users via laptops, desktops, or PDAs. Most people who visit public WLAN areas, however, are not carrying laptops or PDAs. We expect that when WLAN-enabled handsets become popular,

public WLANs and related roaming, billing, and aggregation services will see greatly increased usage.

WLANs and Voice over IP

By definition, WLANs transport IP packets, and they are thus often linked with VoIP in discussions of their use in telecoms. For some telecommunications operators, VoIP is a distraction in the sense that it diverts revenue from traditional voice services rather than increasing total revenue. The reality, however, is that VoIP-related services are rapidly gaining momentum throughout the world (e.g., the Skype VoIP services¹³), and their momentum can not be stopped. This is the case fundamentally because it makes economic sense for voice services to share packet-switching data networks, and because such sharing helps promote deployment of new data services. Telecommunications operators, ought to, at least in the long term, plan on increasing their revenue from nonvoice services, by promoting data services. WLANs' roots in the data world and existing data applications make them well suited to facilitate new data services and to create revenue in new areas such as broadband content, online games, and multimedia streaming services.

The Capacities of Handsets

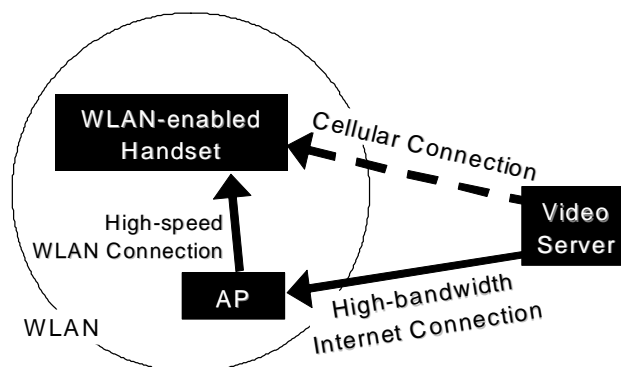
Another issue is how well WLAN-enabled handsets with stringent size constraints can make use of the high-bandwidth link offered by WLANs. In recent years, cellular handsets have substantially expanded their capabilities in computing, storage, display, and peripherals. In fact, they have become one of the most powerful and integrated multimedia devices available to consumers. For example,

with a gigabyte SD memory card, USB drive or hard drive, the storage capacity currently available in today's handsets is already large enough to accommodate an entire 90-minute movie in a compressed video format. With such prodigious storage capacity, handsets will need to use high-bandwidth and inexpensive WLANs for file downloads and uploads.

Figure 11-1 illustrates a scenario in which a handset user downloads a large video file from a remote server over WLAN. Initially, the user accesses a traditional cellular connection. Upon detecting the presence of a WLAN access point (AP), the handset reroutes the connection to the Internet to transfer packets from the server to the AP and the WLAN to transfer packets from the AP, to the handset. The new route will support data transfer at a much higher bandwidth and at a much lower cost to the user. The detection of the AP by the handset can be performed automatically using standard AP-discovery protocols. The rerouting can also be done automatically, without even breaking the connection, using techniques similar to mobile IP.⁶

FIGURE 11-1

Downloading Video via Handset over WLAN

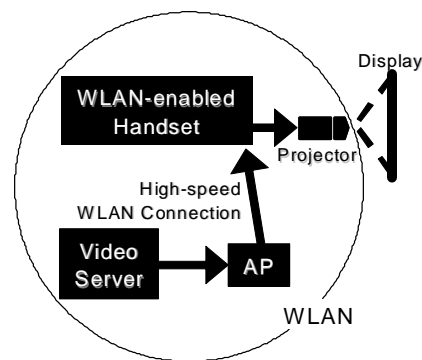


Source: H. T. Kung

A handset can receive compressed streaming video over WLAN from a video server and simultaneously send it, also over WLAN, to a projector that outputs images on a wall-mounted display, or to an LCD display, for easy viewing. (In a *Digital Home* scenario, the video server could be a so-called *home media center*, and the display could use a *home media adapter*.) Figure 11-2 depicts this video-streaming scenario. As we shall see, the handset can also decrypt an encrypted video to implement Digital Rights Management (DRM) functions on the fly. As a recent exhibition on applications of WLAN-enabled handsets demonstrated, today's high-end cellular handsets have enough computing power to perform streaming and decryption functions in real time.⁷

FIGURE 11-2

Streaming Video from Video Server to Projector via Handset over WLAN



Source: H. T. Kung

Moreover, WLANs can provide high-bandwidth, but inexpensive transport to support high-resolution Multimedia Messaging Services (MMS), videophone, and video conferencing, via handsets. Using WLANs, an MMS recipient can afford to receive “pushed” messages automatically without worrying about the

download cost or time, even when such messages are large. Like e-mail receipts, MMS recipients can enjoy the convenience of the automatic receipt of messages.

Consider, too, the use of such handsets in a video-over-IP telephone application. During a telephone session, a user can position the handset's camera to face himself, listen to the other party's voice on the handset's speaker, and watch the other party's image on the handset's display while talking to the handset's microphone. This setup is much simpler and less error-prone than an equivalent setup involving a laptop, desktop, or PDA and all the peripheral devices required for an Internet-based video phone session. With ENUM (standing for "electronic numbering" or "telephone number mapping"), which uses telephone numbers to retrieve domain names, the handset user can have the additional convenience of being able to use the same telephone number for both cellular and IP connections.⁸

As for the power consumption of WLAN-enabled handsets, the applications mentioned above are mostly indoor and stationary, and thus have easy access to power supplies. When the WLAN interface is not in use (such as during a traditional cellular call), a handset will turn it off automatically (or the user can do so) to conserve energy. Moreover, we note that when a handset uses a WLAN in a file download or upload, its WLAN interface will need only be turned on for a relatively short time, due to the WLAN's high bandwidth. Over time WLAN circuits will improve with respect to power consumption when their applications move beyond laptops and desktops to consumer electronics (such as an MP3 player or a digital camera) with stringent energy efficiency requirements.

Indeed, the development of low-power single-chip solutions for WLANs has recently been one of the most active areas in chip design.

Industry Perspectives

Manufacturers are likely to readily appreciate the value of adding WLAN support to handsets. Initially, the market for WLAN-enabled handsets, as for most new products, will be relatively small. Manufacturers of consumer products with rapid innovation cycles will take the lead in the hope of capturing the first-mover advantage—rationale that motivated some sector leaders to provide WLAN support in PDAs and other consumer electronics.

Hardware development for new WLAN-enabled handsets will leverage chips and circuits already developed for various WLAN products. Software systems, by contrast, may present a greater challenge. In particular, handset manufacturers will need solutions for WLAN protocol stacks. The smartphone vendors that use operating systems with built-in support for such protocol stacks (such as Linux, Symbian, and Windows Mobile) will have an immediate advantage.

Cellular telephone operators, on the other hand, may have trouble seeing why they ought to provide WLAN-related services before such services prove themselves viable in the marketplace. Traditionally, operators rely on cutting-edge industry-wide standards in rolling out new generations of technologies and services such as GSM, GPRS, and 3G. In this way they can share the first-mover risk by moving together. But in the case of WLAN, whose development and deployment are mostly pursued in a grassroots fashion, there is no such coherent

and unified cross-industry push. A few visionary operators may break with tradition and aggressively embrace the opportunity of WLANs on their own, but many other telephone operators will probably take a gradual approach to integrating WLAN services. Exactly how the picture will unfold is hard to discern at present. We can be certain, though, that when WLAN-enabled handsets become widely available, operators will step up the pace of integration in order to offer a vast array of new services enabled by these handsets.

A near-term initiative that many telecommunications operators can pursue is the reuse of existing authentication and billing infrastructures by applying them to WLAN services. For example, GSM cellular phones' SIM cards can be used for authentication and charging purposes for both WLAN access and content services that use WLANs for content delivery. Also, a WLAN-enabled handset user will be able to rent or purchase a video and retrieve it over a WLAN utilizing his or her subscription account with a telecommunications operator.

Alternatively, the user can pay via his or her telephone subscription account to download content covered by DRM agreement using a handset with built-in DRM support. For instance, the user may purchase a content key for a piece of MP3 music or an MPEG-4 video using his telephone subscription account, and then use his handset to decrypt otherwise unplayable content. DRM rules could be flexible: for instance, they could specify that content downloaded to the handset can only be uploaded to other devices twice and played a maximum of 10 times within the initial six months.

Cellular operators' authentication and billing systems are particularly useful for these applications, since their per-user rather than per-household setup is more suitable to mobile users who may be away from home. The system can truly support a simple-to-use "single-sign-on" mechanism that offers great convenience while providing a reasonable level of security and privacy. In addition, to the application service providers, SIM card based authentication provides a way to track customers behavior such as their buying habits on an individual basis.

ISPs have a longstanding interest in VoIP services—an interest that has recently substantially increased, in part due to VoIP's success in countries like Japan, which has millions of VoIP subscribers. Another explanation for ISPs' growing interest in VoIP is the standardization of new protocols like Session Initiation Protocol (SIP) and Electronic Numbering (ENUM), which facilitate deployment of VoIP services: the SIP protocol provides end-to-end signaling over the IP network and the ENUM system allows search by telephone number through the Domain Name Service (DNS) for such related information items as name, IP address, e-mail address, fax number, street address, personal interests, and the like.⁹ A given ENUM search may not retrieve all of these items, for reasons of privacy protection (but the ability to use a telephone number to retrieve a domain name represents a significant convenience for users.) These standards enable VoIP service providers to use heterogeneous systems to provide a variety of new data and voice services.

However, VoIP still faces a formidable obstacle: the inconvenience of having to find a headset, gateway, or computer to use VoIP services. Some recently released USB and Wi-Fi VoIP handsets and embedded VoIP boxes have mitigated the problem somewhat. WLAN-enabled handsets, which support both cellular and WLAN services, will completely eliminate this obstacle.

Fixed-wire phone operators can also benefit from WLAN-enabled handsets. Subscribers often choose to make cellular calls even when a fixed-wire phone is readily available; it has been reported that in the United Kingdom about 30 percent of mobile calls are actually made from the user's home.¹² It is also commonplace to call a person at his or her cellular rather than fixed-wire number to ensure that the the person called will retrieve the caller ID from the cellular handset and pick up the call. The use of dual-mode WLAN-enabled handsets in VoIP can thus help offset fixed-wire providers' loss of subscribers and minutes to cellular providers. Furthermore, fixed-wire telephone operators will be able to provide voice services beyond the boundaries of their own local-loop facilities: they can provide VoIP services over DSL, Ethernets, or other data lines, or use WLAN as a local loop.

Cable operators also express interest in providing VoIP services. In Japan, several major VoIP service operators are backed by cable operators. Moreover, some of the cable set-top box's Digital Rights Management functions can migrate to a WLAN-enabled handset with built-in DRM support, as we saw earlier. Incorporating DRM functions in a handset is particularly natural when the handset also acts as a remote controller for a settop box.

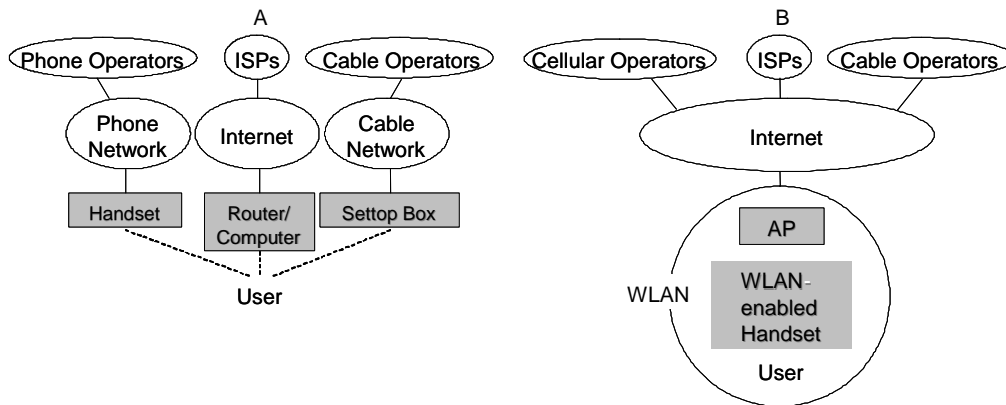
A new generation of service providers, often called "aggregators", is focusing on WLANs. Through franchise arrangements, aggregators combine the services of multiple WLAN operators under a single brand name and also provide roaming support to customers. Thus aggregators' customers no longer perceive hotspots as islands but as a large, unified wide-area network. The franchises can wield its technology and marketing power to set up new hotspots quickly, and can exercise aggregated buying power to negotiate favorable back-haul network fees. As we have mentioned, usage of hotspots will increase greatly when WLAN-enabled handsets become widely available. WLAN aggregators are likely to be major players in telecommunications services within a few years.

Three-in-One WLAN-Enabled Handsets as a Convergence Point

This picture has emerged from our discussion thus far: WLAN-enabled handsets offer the triple functions of a traditional cellular voice phone, an Internet-download-and-multimedia-communications device, and a cable set-top box's DRM capability. These 3-in-1 handsets thus represent a convergence point for three networks: a phone network, the Internet, and a cable network. Figure 11-3a illustrates the traditional setup whereby a user uses separate devices and network paths for services on the three networks. With a WLAN-enabled handset, as Figure 11-3b shows, a user will be able to reach all three networks at once over WLAN.

FIGURE 11-3A AND 3B

Alternate Network Access Models



Source: H. T. Kung

Clearly, WLAN-enabled handsets represent a keystone in WLANs' integration into telecoms. With these handsets, operators will be in a stronger position to roll out WLAN-related services.

An Agenda for the Near-Term Future

Accelerating the integration of WLANs into telecommunications providers will require further efforts in several spheres of technology, applications, and regulatory policy.

In handset technology, work in the following areas would be essential in realizing our vision about WLAN-enabled handsets and their use as outlined above:

- *WLAN-enabled handsets.* To achieve high performance these handsets should be *integrated* GSM/WLAN, GPRS/WLAN or 3G/WLAN handsets, rather than cellular handsets with plug-in WLAN modules. Furthermore,

such an integrated handset should allow simultaneous use of both WLAN and GSM/GPRS/3G at the same time.

- *Power-efficient WLAN circuits and MAC-layer protocols.* To support VoIP over WLAN, the power consumption for transmitting or receiving should be no more than 200mW, and that for simply listening should be much lower. This may be achieved with a low bit rate comparable to what is required for VoIP sessions.
- *WLAN resource discovery and control protocols.* WLAN-enabled handsets should be able to discover and control nearby resources such as projectors and data servers automatically.
- *WLAN/WLAN and WLAN/cellular handoff protocols.* These handoff protocols can support applications such as VoIP where connections will need to be maintained when a handset user moves from WLAN to cellular network or another WLAN, and vice versa.
- *Audio and video streaming.* For example, a WLAN-enabled handset can stream audio or video over WLAN to a TV or speaker via a WLAN home media adapter.
- *Latency-sensitive WLAN protocols.* For applications, which have stringent quality of service (QoS) requirements such as VoIP, we will need to minimize or eliminate delay uncertainty introduced by current protocols such as Request To Send/Clear To Send (RTS/CTS), and/or provide priority scheduling.

- *WLAN Virtual Private Networks (VPN)*. Like a laptop/desktop, a WLAN-enabled handset should be able to set a VPN connection to a remote server for authentication and security purposes.
- *New peripheral interfaces such as various sensing devices*. For example, via an interface to a Radio Frequency Identification (RFID) reader, a WLAN-enabled handset can serve as an always-on mobile server that can identify RFID-tagged objects in the nearby area.

We also need to address new opportunities, such as DRM and handset controllers for various Wi-Fi appliances. Perhaps, given the popularity of Apple's iTunes/iPod online music configuration, we can anticipate another successful business model based on WLAN-enabled DRM handsets. Last but not the least is the need for establishing a certification process that can certify WLAN-enabled handsets and related software.

In the application and services arena, there are multiple directions to pursue. One would address vertical markets in facility security, manufacturing, education, health care, retail, exhibition halls, tourist spots, and warehouse management, spheres in which WLAN-enabled handsets could serve the functions of communications (for instance, walkie-talkies), monitoring and tracking, and personalization in a local environment. These handsets can incorporate RFID readers to further enhance their capability to serving these markets. Such handsets would need to compete with existing solutions based on PDA devices and low-tier Digital Enhanced Cordless Communications (DECT) phone network or PHS

cellular systems. WLAN devices that do not emit strong radio interference will be necessary for environments like factories and hospitals with electronically sensitive instruments.

A new generation of WLAN-enabled operator-offered services will emerge. These might include SIM-based authentication, charging, and billing for WLAN access and WLAN-related services ("single sign-on"); MMS push, interactive cellphone games, and video telephone conferencing over WLAN; and multimedia content-download service using WLAN-enabled DRM handsets. If corresponding versions already exist on cellular phone networks or the Internet, these applications will need to be extended to WLAN environments. For example, it will be possible to port digital TV or some popular interactive online games on the Internet to WLAN-enabled handsets.

Integrating WLAN-enabled VoIP handsets in enterprises and educational institutions should be an immediate goal while fixed-wire phone companies and cable operators are developing public systems capable of using these handsets.¹⁰ These VoIP systems can benefit from new protocols such as SIP and ENUM.

A WLAN-enabled handset will offer enormous versatility as a consumer electronics device. With its built-in speaker, microphone, camera, and recording capabilities, such a handset is a natural monitoring device for a baby's room, a patient-care area, or a building entrance. A WLAN-enabled, handset-based monitoring system can afford an always-on network connection and can transport high-resolution pictures and videos. With its large storage capacity, a handset will function as portable storage for data and video files, similar to today's USB

storage devices. Unlike USB storage, however, a handset can transfer files or stream video over WLAN to servers, projectors, or displays.

A WLAN-enabled handset is also a versatile control device. It can be a remote controller for any home appliance, entertainment device, or gate control with a WLAN interface. Through the attached SIM card, moreover, the handset-based remote controller can support authenticated control functions.

Regulatory initiatives will be necessary to ensure that public unlicensed spectrums for WLAN applications are sufficient and safe. For example, new regulations will be needed to discourage malicious radio interference in a WLAN environment. In the future, technology advances will allow WLANs to operate at speeds of a gigabit per second or more; thus allocation of additional unlicensed spectrum will be needed to support increased bandwidth and quality of service over WLAN.

Regulation will also need to address the management of telephone numbers. A user of a WLAN-enabled handset could use several telephone numbers on his or her handset (cellular number, VoIP number, home and work fixed-wire phone numbers, and instant messaging number). We will need to develop schemes to allocate these numbers and to encourage their convergence, perhaps through systems like ENUM.¹¹

Conclusion

Integrating WLANs into telecommunication systems promises extraordinary benefits for end users. With a WLAN-enabled handset, a cellular phone user will have immediate and convenient access to a multitude of cost-effective broadband

WLAN applications and services without having to rely on a PDA or a PC. These handsets will serve as a common access device for the Internet, cable, and phone networks. The single-sign-on and always-on features of WLAN-enabled handsets are certain to inspire new application and business initiatives.

Handset manufacturers, together with ISPs and fixed-wire operators and WLAN aggregators, are expected to be among the first to move towards integration, with WLAN-enabled handsets as an initial focal point. The initial market for WLAN-enabled handsets will probably outstrip the market for PDAs within a few years, given that these next-generation handsets will include a WLAN interface and PDA-like functionality. When such handsets become widespread, other sectors—such as public WLANs—will take off as traditional cellular operators and WLAN aggregators aggressively promote WLAN services. All telecom sectors, including cellular operators, should be prepared to offer services that incorporate WLAN capabilities.

Endnotes

¹ See “3G is Safe from Wi-Fi,” 20 October 2003. Available at

<<http://www.3g.co.uk/PR/Oct2003/5974.htm>>; and W. Lehr and L. W. McKnight, “Wireless Internet Access: 3G vs. WiFi?” Cambridge: Center for eBusiness, Massachusetts Institute of Technology, 2002. Available at <<http://ebusiness.mit.edu>>

² B. Strachman, “Voice over WLAN: Will the Market Finally Answer?” In-Stat/MDR 14 March 2003. Available at <<http://www.instat.com/>>

³ See Brad Smith, “Intel Shows Advanced Smartphone Concept,” *MobileMag* 22 September 2003, available at <<http://www.mobilemag.com/content/100/340/C2063/>>; “MiTAC Mio 8380 First

Windows Powered Clamshell Smartphone,” *MobileMag* 21 July 2003, available at <<http://www.mobilemag.com/content/100/340/C1845/>>; “Seamless Switching of WIFI and Cellular for Voice, Data and Real-time Video Conferencing Services,” Calypso Wireless Inc., available at < <http://www.calypsowireless.com/WP.pdf>>. (accessed August 2003); and T. Marshall, “DoCoMo Tests 3G/WiFi Dual-mode Phones,” available at T. Marshall, “DoCoMo Tests 3G/WiFi Dual-mode Phones, 12 September 2003. Available at < http://www.telecomtv.com/newComms.php?cd_id=341> (Accessed 6 June 7, 2004.

⁴ The exhibition was the iBakeoff: WLAN-Cellular Network Integration Exhibition, held in Taipei, Taiwan, on 9 January 2004. For a description of the smartphone, see “MiTAC Mio 8380 First Windows Powered Clamshell Smartphone,” *MobileMag* 21 July 2003, available at <http://www.mobilemag.com/content/100/340/C1845/>, 2003.

⁵ M. Buddhikot, G. Chandranmenon, S.J. Han, Y.W. Lee, S. Miller, and L. Salgarelli, “Design and Implementation of a WLAN/CDMA2000 Integration Architecture,” *IEEE Communications Magazine* 41 (11): 90-100.

⁶ C. Perkins, ed. “IP Mobility Support,” *RFC 2002, Internet RFC/STD/FYI/BCP Archives*, available at <http://www.faqs.org/rfcs/rfc2002.html>.

⁷ iBakeoff: WLAN-Cellular Network Integration Exhibition, Taipei, Taiwan, 9 January 2004.

⁸ J. Morris, “Enum: Mapping Telephone Numbers Onto The Internet: Potential Benefits with Public Policy Risks,” Center for Democracy and Technology, April 2003, available at <http://www.cdt.org/standards/enum>.

⁹ D. Sisalem and J. Kuthan, “Understanding SIP,” 2002, available at <http://www.iptel.org/sip/siptutorial.pdf>; and J. Morris, “Enum: Mapping Telephone Numbers Onto The Internet: Potential Benefits with Public Policy Risks, Center for Democracy and Technology, April 2003, available at <http://www.cdt.org/standards/enum>.

¹⁰ V. Lipset, “Dartmouth Intros Wireless VoIP,” Wi-Fi Planet, 26 September 2003, available at <http://www.wi-fiplanet.com/columns/article.php/3084501>.

¹¹ J. Morris, "Enum: Mapping Telephone Numbers Onto The Internet: Potential Benefits with Public Policy Risks," Center for Democracy and Technology, April 2003, available at <http://www.cdt.org/standards/enum>.

¹² "The Everywhere Phone," BT Group available at <http://www.btplc.com/Innovation/Mobility/everywhere/> (accessed 7 June 2004).

¹³ S. Baset and H. Schulzrinne, "An Analysis of the Skype Peer-to-Peer Internet Telephony Protocol," Columbia University Technical Report CUCS-039-04, September 2004, available at <http://www1.cs.columbia.edu/~salman/publications/cucs-039-04.pdf>.

¹⁴ 3GPP TS 22.934, "Feasibility study to Wireless Local Area (WLAN) interworking," V1.1.0, 2002