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Assessing the widespread deployment and increasing use of mobile services.

Evolution and Emerging Issues in Mobile Wireless Networks

In recent years, wireless network technologies have experienced several exciting innovations and will continue to represent a rapidly growing sector in the near future. Expanding on current wireless network infrastructure, today's third-generation (3G) mobile networks offer broadband transmission with speeds of up to 2Mbps in some areas of the world. However, the international 3G networks standard, IMT-2000, defines no less than five incompatible 3G wireless standards, three of which are currently in different stages of realization, thus complicating the well-known problem of interoperability of wireless networks.

Currently, 3G and 3.5G (HSDPA) wire-

less access systems provide basic data services, along with voice and messaging capabilities. However, telecommunications vendors and service providers are researching and developing a next-generation, truly broadband wireless cellular system, known as the fourth generation (4G) [7]. The 4G system would allow for significantly higher bit rates per user (ranging from 10Mbps–100Mbps), and would support the interoperability of diverse and heterogeneous wireless and mobile networks. This next generation of wireless technologies promises extensive opportunities for wireless services and applications, namely m-commerce and m-business. In the future, mobile tools, mobile e-services, and wireless Internet protocols will mark the next major set of developments in decision support systems, thereby expanding the accessibility of tools to decision makers.

Brief History of Wireless Services

In the early 1970s, wireless service offerings were a scarce and expensive form of communication. The first wireless service in the U.S. was Improved Mobile Telecommunications Service (IMTS) [2], which consisted of a 100-watt base station centrally located in a service area. To complete a call, operator assistance or manual selection of an available frequency was required. The rotary telephone was mounted on the dashboard of the vehicle and equipped with 12 buttons for manual selection of an available radio frequency. This early service was a party-line service in that the search for an available radio frequency meant a user had to listen for an available channel before initiating a call. Since the spectrum was a limited resource, early subscriptions to mobile communications required a customer to be placed on a waiting list for service. The service request was generally granted to those in greatest need of mobile communications.

Customer service offerings have changed dramatically since the first commercial offering. At the time of commercial launch, voice mail services were offered for additional fees; however, as the wireless services became more competitive, these offerings were bundled with basic service. In contrast, today's handsets are feature-rich, capable of special ring tones, games, music, video, Karaoke, TV, cameras, and voice-recognition features. Most handsets also have data capabilities to send and receive data to and from a laptop. Overall, the features offered with wireless services have progressed from voice-only service to a comprehensive service suite [8].

Similarly, as 3G matures and 4G evolves, mobile commerce now includes location-based services (finding services, people, products, mapping/directions, and information), mobile entertainment services (video-on-demand, music, multiuser games), mobile financial applications (banking, brokerage, cash transactions), proactive service management, and mobile auctions. Wireless operators are introducing digital multimedia broadcasting, a multicast process that captures digital broadcasts and delivers simultaneous audio and video service to mobile devices in motion, such as cellular phones, PDAs, and terminals in automobiles [5]. These services are likely to be user-centric and highly personalized, context and location-aware, highly transaction-oriented, and more global in nature. The potential capabilities of current and emerging wireless and mobile networks will significantly affect the offering, adoption, and deployment of m-commerce and future mobile services.

Evolution of Wireless Networks

Current users are served by many different standards: first-generation (1G) and second-generation (2G) networks based on one or more versions of wireless communication protocols, including frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and 3G via CDMA (cdma 2000, W-CDMA, and TD-SCDMA). Notably, 3G specifications offer the flexibility needed by both existing operators (to evolve their 1G and 2G networks toward 3G services) and satellite or

terrestrial providers (to design new 3G systems). The radio specifications allow five different choices, carefully designed to help existing 1G and 2G wireless systems to interoperate with or evolve into 3G systems. However, the worldwide migration to 3G has slowed due to operators' perceptions of limited market need, lack of incentives to carriers and operators, heavy capital investment made in the existing 1G and 2G wireless systems, auctions of frequency spectrum licenses, and the monopolization of wireless carriers in many countries. Nonetheless, movement to 3G is now well under way globally.

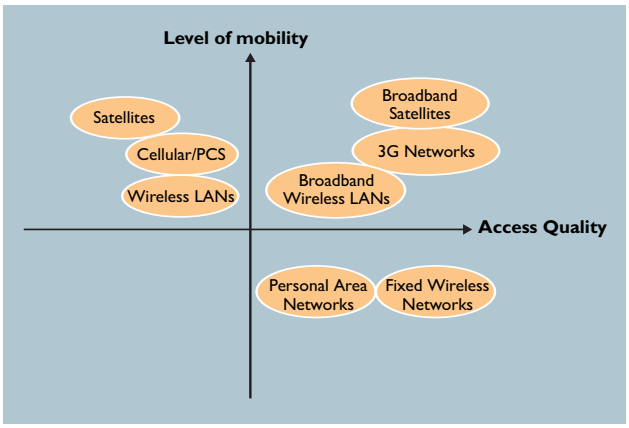

Figure 1. Access quality and mobility in current mobile and wireless networks.

From a broader perspective, wireless networks also include wireless LANs, satellites, fixed wireless networks, and personal area networks, for which multiple standards exist. Figure 1, which outlines the level of mobility and access quality of current and emerging networks, indicates quality of service influences technologies and its evolution.

To support roaming across heterogeneous wireless networks and packet-switched wireless communications, there is a growing interest in the design and development of 4G wireless networks [7], which will allow users to move from one type of wireless network to another using multi-network devices or interconnected wireless networks. The factors that distinguish the 4G networks are roaming across networks, IP interoperability, and higher speeds. While 3G networks are currently being deployed, 4G networks are scheduled for deployment between 2008 and 2010. Hopefully, this time frame will allow ample time to sort out incompatibilities and other problems (for 4G wireless references, see www.s3.kth.se/radio/4GW). A comparison of the four generations of mobile wireless technologies is shown in Table 1; Table 2 shows different types of wireless and mobile networks.

The Generation	Access Protocols	Key Features	Level of Evolution
1G	FDMA	Analog, primarily voice, less secure, support for low bit rate data	Access to and roaming across single type of analog wireless networks
2G and 2.5G	TDMA, CDMA	Digital, more secure, voice and data	Access to and roaming across single type of digital wireless networks and access to 1G
3G and 3.5G	CDMA2000, W-CDMA, HSDPA, TD-SCDMA	Digital, multimedia, global roaming across a single type of wireless network (for example, cellular), limited IP interoperability, 144Kbps to several Mbps	Access to and roaming across digital multimedia wireless networks and access to 2G and 1G
4G	TBD	Global roaming across multiple wireless networks, 10Mbps-100Mbps, IP interoperability for seamless mobile Internet	Access to and roaming across diverse and heterogeneous mobile and wireless broadband networks and access to 3G, 2G, and 1G

Table 1. A comparison and evolution of 1G, 2G, 3G, and 4G wireless networks.

For all generations of wireless solutions, integration and interoperability are necessary for increasing the network coverage and ensuring reliable access. Two issues to consider are compatibility among wireless networks and access to multiple networks using special devices. Achieving compatibility among protocols and networks is much more difficult due to the significant differences in the protocols, coverage, and speeds of different wireless networks. Additionally, wireless carriers have no incentive to share feature transparency between systems, as this presents issues of competition, competitive advantage, and revenue reconciliation between carriers. Access to multiple networks using special devices is more common, since many wireless devices have functionality to access one or more wireless networks. For example, although IEEE 802.11a wireless LAN is not compatible with 802.11b, dual-band adapters can be used allowing access to both 802.11a and 802.11b or 802.11g networks.

In 4G networks, the access to multiple wireless networks could also be facilitated by the use of an overlay network or by having intelligence in the networks. This would obviate having multiple interfaces or adapters in user devices. A possible architecture for 4G wireless networks is shown in Figure 2. Universal access points are used to provide access to one of several wireless networks. The choice of a certain wire-

	Personal Area Network (PAN)	Local Area Network (LAN)	Metropolitan Area Network (MAN)	Wide Area Network (WAN)
Technology	Bluetooth Ultra-wideband (UWB)	802.11b 802.11a 802.11g a.k.a. Wi-Fi	802.16 802.16a 802.16e a.k.a. WiMAX	GSM GPRS CDMA 2.5G 3.5G
Data rates	Medium data rates 1Mbps to 2Mbps	High data rates 11Mbps to 54Mbps	Very high data rates Quality of service up to 268Mbps	Low to medium data rates 10Kbps to 2.4Mbps
Range	Very short range 3m (~10 feet)	Short range 100m (~300 feet)	Medium range 50km (~31 miles)	Long range Global
Connectivity	Notebook to PC to peripherals Devices to systems	Computer to computer and the Internet	LAN or computer to high-speed wire line Internet	Smart phones and PDAs to WANs and the Internet

Table 2. Categories of wireless networks.

less network can be user-specified, location-dependent, or based on an application's quality of service requirements [7]. So while 4G is promising, there are still problems, and while it is evolving, there are yet other plans on various drawing boards.

Wi-Fi and WiMAX: Threats or Opportunities for Wireless Carriers?

One of several interesting developments in the domain of wireless communications is the rapid acceptance of the IEEE family of 802.11 standards, also called Wi-Fi (short for wireless fidelity), wireless LAN, or WLAN. Wi-Fi was designed as an inexpensive alternative for the hardwired Ethernet because buildings do not need to be wired or rewired.

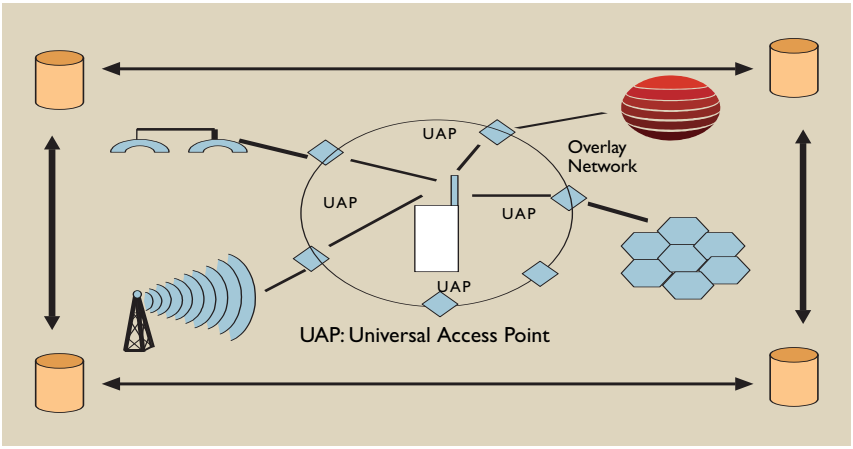

Figure 2. A possible 4G architecture using overlay network.

Wi-Fi has quickly gained popularity among small companies and individuals who extended coverage by setting up Wi-Fi access points, or "hotspots," in urban neighborhoods. It consequently gained support of industry giants, such as Intel, Cisco, Microsoft, IBM, AT&T, Verizon Communications, T-Mobile USA, SBC Communications, and many others, not to mention a number of smaller players. Rapid acceptance has also been facilitated by the proliferation of inexpensive radio cards, and most new laptops and PDAs have built-in radio cards. According to Gartner, worldwide PC shipments with built-in wireless LAN capability should reach 93% by the end of 2009.

Pyramid Research predicts the global number of Wi-Fi users could top 700 million in 2008 [1]. In the U.S., Wi-Fi users would outnumber 3G users 180 million to 90 million that year, according to Pyramid. In December 2004, Taichung city in central Taiwan became the island's first major city to have Wi-Fi coverage by deploying one of the first wireless mesh technology areas in the world. Wi-Fi covers 80% of the city and is provided by the city and Yaw Jeng Technology with more than 1,700 hot spots [4]. Similarly, the city of Philadelphia established a nonprofit Wireless Philadelphia, which selected EarthLink to build, operate, and maintain the citywide free or low-cost broadband wireless network covering 350 sq. km. (135 sq. miles), scheduled for completion by late this year (for more information, see www.wirelessphiladelphia.org/about_wireless.cfm). Similar projects abound in many municipalities worldwide. MuniWireless listed 81 operational municipal wireless networks and 259 other initiatives on March 31, 2007 in the U.S. alone (more information is available at www.muniwireless.com).

But the forecast is not entirely optimitic: cable and phone companies are terrified of the "free" cloud. They want control over rates and competition and have tried to prevent such projects through litigation. Another problem is that no profitable business model for carriers has yet been identified. Although the Wi-Fi service in San Francisco was initially introduced with a promise of being free, to everybody, the model evolved into a slow, but free advertisement-supported service offered by Google combined with a faster, but subscription-based service from EarthLink. These networks were planned to be implemented by the end of 2006, but were delayed by difficulties in negotiations with the city administration. National Wi-Fi network is even less likely. Because of short range,

about 700 Wi-Fi hotspots would be needed to cover the same area as one cellular base station. If we assume that a nationwide mobile phone network consists of 10,000 base stations, it would take seven million Wi-Fi hotspots to provide the same coverage. The backhaul costs alone for seven million Wi-Fi hotspots would be astronomical.

Wi-Fi is not currently a viable substitute for 3G wireless service, which offers broadband speeds in most U.S. markets. Wi-Fi and cellular wireless services are complementary, as they can exist and succeed together, but only after roaming, billing, security, seamless authentication, handovers, and other such issues are resolved.

As mentioned earlier, three versions of Wi-Fi service exist and more are coming. Both 802.11a (5.8GHz) and 802.11g (2.4GHz) offer up to 54Mbps using Orthogonal Frequency Division Multiplexing (OFDM), where 52 different carriers are simultaneously used in industrial, scientific, and medical (ISM) radio bands. This allows for higher bit rates, as all carriers are used by a single user (for some time). This also overcomes multi-path interference. OFDM is likely to be the transmission method for future higher bit rate LANs. It should be noted that bit rates of wireless LANs are limited by the size of spectrum at ISM bands (83.5MHz at 2.4GHz band and 125MHz at 5.8GHz). One way to overcome bit rate limitation is to use Multi-input, Multi-output (MIMO) antenna technology, which uses several antennas to create multiple streams of data. This is under consideration for IEEE 802.11n, the next set of standards for higher bit rate (typical 200Mbps, maximum 500Mbps) wireless LANs.

If the evolution of Wi-Fi is interesting, the appearance of Worldwide Interoperability for Microwave Access (WiMAX) is even more so. This technology is being standardized by the ongoing work of IEEE's 802.16 Working Group under the name Wireless Metropolitan Area Network (WirelessMAN). While broadband wireless technology is not new, and several proprietary solutions have been available for some time, the standardized technology is expected to gain broad market acceptance. This expectation is facilitated by the WiMAX Forum, an industry association promoting the technology and verifying its compliance with the IEEE standards. The first products were certified in January 2006, and so far 28 different products from 12 manufacturers have been verified to comply with the standards by the WiMAX Forum labs. Again, large vendors, such as Intel, Nokia, Motorola, Alcatel-Lucent, and Nortel Networks, are backing the technology. Gartner recently predicted the revenue from sales of WiMAX equipment will grow to more than $6.2 billion by 2011, and that the global number of users will reach 85 million in the same year [3].

WiMAX was originally conceived as a wireless metropolitan-area network technology providing up to 50km (31 miles) service range, with shared data rates of up to 70Mbps and a peak of up to 268Mbps. The core WiMAX standard was developed in 2001 and supported line-of-sight transmission in the 10GHz–66GHz frequency range. Amendment 802.16a supporting non-line-of-sight transmission in the range between 2GHz–22GHz bands was ratified in January 2003. In June 2004, amendment 802.16d—consolidating revisions "b" and "c" for quality of service, testing, and interoperability—was also ratified and is known as IEEE 802.16-2004. Amendment 802.16e-2005, which supports mobility, was concluded in 2005. Despite the expectations, however, WiMAX as it is currently defined will not deliver 70Mbps, mobility, and 50km range at the same time. Peek downstream data rates are anticipated at 12Mbps and upstream 2Mbps–5Mbps, but actual bit rates will most likely average 2Mbps–4Mbps. Even so, this technology may influence the evolution of cellular telephony.

WiMAX will function on both unlicensed and licensed frequencies, but for industrial use the licensed spectrum will be used. The WiMAX forum is trying to focus development on the 2.4GHz and 5.8GHz bands of unlicensed frequency spectrum and the 2.5GHz and 3.5GHz bands of licensed spectrum. An effort is also being made to secure some spectrum below the 2GHz band, which would allow for greater range, but this is likely to be problematic [6].

The promise of large range and high bit rates attracted a great amount of attention and caused some possibly undue speculation. Some suggested that WiMAX technology may turn out to be the 4G of wireless communications. Indeed, in August 2006 Sprint Nextel announced it was investing up to $3 billion in mobile WiMAX technology to provide nationwide broadband wireless services covering 100 million people in 2008. Sprint Nextel is promoting this network as 4G technology at a time when the International Telecommunication Union, the general telecommunications standards body, has not yet published 4G specifications. Supported by Motorola,

Samsung, Intel, and later Nokia, this initiative may split 4G standardization efforts and conflict with the initiatives of international collaboration agreements executed by working groups known as 3GPP and 3GPP2. The first is defining the evolution path toward 4G for the global community of UMTS vendors, operators and users, while 3GPP2 is doing the same for the CDMA community. Sprint Nextel is attempting to bypass 3GPP and 3GPP2 standards and establish WiMAX as an alternative global 4G standard.

Many other companies around the world are implementing or testing WiMAX technology. For example, Intel Capital gave Craig McCaw's company Clearwire $699 million to accelerate the deployment of a national WiMAX network. Chicago, Washington, D.C., and Baltimore are the first cities to get this new high-speed wireless service, which will extend to other cities next year and nationally in three years. By the end of 2008, Sprint Nextel hopes to have coverage available to 100 U.S. cities.

In December 2006, Intel demonstrated its WiMAX Connection 2300 chipset design and showed an Intel Centrino Duo mobile technology-based laptop with mobile WiMAX (IEEE 802.16e-2005), Wi-Fi (IEEE 802.11n), and high-speed downlink packet access (HSDPA) 3G capabilities, and successfully accessed the Internet at broadband speeds over a mobile WiMAX network. Intel is now focusing on validating and testing the chipset and plans to sample both cards and module forms beginning in late 2007.

An earlier version of mobile WiMAX standard called WiBro (Wireless Broadband) was developed in South Korea but was harmonized with the IEEE development to become interoperable with other 802.16e-2005 products. WiBro, which operates in 2.3GHz, is now used as a name of a service based on 802.16e that has been rolled out in South Korea. Similarly, European Telecommunications Standards Institute created a standard called HiperMAN w(High Performance Radio Metropolitan Area Network), which has also been harmonized with IEEE 802.16e-2005.

Conclusion

Mobile and wireless networks have rapidly evolved all around the world. South Korea and Japan are currently the world leaders, having introduced 3G wireless as early as 2000 and 2001, respectively. As of September 2006, Japan became the first country to have more than 50% of its subscribers using 3G; South Korea is a close second in this ranking. Voice services still generate the majority of revenue. However, revenue from data-related services in the U.S. is growing by an annual rate of 49%, while revenue from voice is growing by 11.2%. Many interested observers are watching wireless evolution in Korea and Japan as they experiment with a variety of new types of services in search of a successful application.

Mobile services, including m-commerce, will be significantly influenced by comprehensive and dependable global access to wireless networks at higher bit rates. The current and emerging wireless networks, including 3G, 3.5G, and possibly 4G, are likely to result in a widespread deployment and utilization of mobile services, especially in the era of digital multimedia broadcasting (DMB). As of November 2006, satellite DMB had one million subscribers and terrestrial DMB 2.5 million. The DMB or Digital Video Broadcasting-Handheld (DVB-H), or MdeiaFLO phone, is seen as the newest personalized gadget, as it offers consumers the option to choose from TV and audio stations on demand while simultaneously making phone calls. Thus m-commerce will bring about a new paradigm shift, since DMB will be incorporated into all facets of daily activities. C

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