Introduction

It is doubtful that there has ever been a technology sector which has as rapidly and pervasively transformed the lifestyles of the majority of the earth’s population as has information technology, particularly through wireless telephony and Internet connectivity. The statistics of users of these two services in the decade which straddles the start of the new millennium have been staggering. From the start of 1995 to the end of 2005, the number of cellular phone subscribers has risen from the low tens of millions, mostly in the U.S., to almost two billion [1], nearly a third of the world’s population. The numbers of mobile phone users in Asia and Europe have each exceeded those in North America, with China being first among all nations and the U.S. only second. Of course, population sizes matter with penetration of the U.S. population at about 70%, while that of China, with five times the population, at less than 25%. But this bodes well for continued growth in the latter as well as in India the other Asian mega-nation.

Internet accessibility has enjoyed equally remarkable growth in the past decade. From only a few million users for predominantly business and scientific purposes, accessibility has become an almost ubiquitous feature of today’s personal computer and probably the primary attraction for consumers. The number of persons who claim to have accessed the Internet is approaching one billion [2], though frequency and extent of usage is unspecified. Again North America leads in penetration with 68% of its population so claiming, whereas Asian penetration is barely 9%, though already exceeding our continent’s user numbers and growing at nearly double its rate. Numbers aside, the Internet’s potential impact on society is much greater than that of mobile voice connectivity, though it has yet to achieve the average consumer’s perception. Ultimately, much of this benefit will depend on “broadband” connectivity, meaning high speeds and very low throughput delays, currently enjoyed by a minority of the worldwide users.

Given these dramatic growth statistics for wireless telephony and for broadband web-based information and services, the popular view is that a marriage of the two will inevitably lead to even more rapid acceptance. A thoughtful analysis of current trends and review of the disparate histories of the two technologies may lead to another conclusion.

Wireless telephony

Mobile telephony service for consumers has been available for about a quarter century, with analog telephony being predominant in North America until well into the nineties

1. GSM Association
2. Internetworldstats.com
and practically non-existent elsewhere. Digital mobile telephony began in Europe in the early nineties with GSM and by the end of the century had reached worldwide acceptance and predominance. GSM, originally an acronym for “Groupe Speciale Mobile” and later renamed “Global Service for Mobiles”, resulted from the European Telecommunications Standards Institute’s (ETSI) initiative to create a continent-wide standard as well as spectrum allocation for all wireless carriers in the European Community. This digital technology had two defining features: the GSM standards committee felt no need to be backward compatible with a virtually inexistent analog technology and it selected a version of time-division multiple access (TDMA) somewhat inspired by the technology adopted by the communication satellite designs of the seventies. In contrast with frequency-division multiple access (FDMA) which apportions a slice of frequency spectrum to each user, which is the only feasible method for analog technology, TDMA apportions a combination of time and frequency slices to users. In the GSM system frequency slices are about eight times as wide as for analog FDMA, permitting the time sharing of each frequency slice by eight TDMA users. On the other hand, North American carriers had no technology constraints for digital service. They were each allotted, by the FCC, 10 MHz of spectrum, later increased to 12.5 MHz, but left free to choose the digital technology to employ. Committees of the Telecommunications Industry Association (TIA) were entrusted with developing standards. Since by the late eighties there were already several million subscribers to analog cellular, they chose to be strictly backward compatible with the frequency allocations which were only 30 KHz wide and thus quite narrowband. They nevertheless followed Europe’s lead in selecting TDMA, but one that was severely bandwidth constrained and thus weakened. This standard is designated by its standards document number as IS-54 but will be referred to here as NA-TDMA.

Another school of thought in North America, driven more by the communication systems theory which was conceived in the late forties and matured through the space communication evolution in the subsequent forty years, embraced a truly broadband signaling approach which, in place of the strict analog bandwidth constraints, chose to apportion a fraction of the cellular band, 1.25 MHz out of the total 12.5 MHz to a different digital technology, code-division multiple access (CDMA), which spreads the original narrowband digital signal over the full bandwidth. Being thus 40 times as wide as the analog and NA-TDMA signals, with appropriate digital signal processing this provided two significant advantages: relative immunity to multipath fading, the bane of mobile communication, and through interference suppression the ability to support many more users in a given spectral allocation—over an order of magnitude more than analog and about triple the sturdier version of TDMA, namely GSM. Needless to say, this “upstart” technology was not well received by either the European or American standards bodies and other critics, but ultimately after a number of successful demonstrations and numerous forums over a period of three years, the North American TIA accepted the alternate CDMA-based standard alongside the earlier adopted NA-TDMA standard. This left the decision on which digital technology to employ up to individual carriers. A number chose CDMA but the majority chose the NA-TDMA evolution. As it was, analog was sufficiently entrenched in North America by the mid nineties that carriers were very slow in adopting the digital standards, in marked contrast to Europe and parts of Asia.
Surprisingly, it was South Korea which embraced CDMA as its only digital standard and soon had tens of millions of subscribers. This not only gave CDMA its needed support to stimulate the manufacturing base, but it also propelled Korean industry into the forefront of wireless manufacturers as well as service providers, which was partly responsible for turning the nation from an importer to a major exporter of electronics. By the end of the century there were nearly 100 million subscribers to CDMA service worldwide with the bulk divided about equally between Korea and North America [3]. Of course, GSM with its European base had by this time expanded worldwide and reached nearly 500 million subscribers [4]. Technology aside, GSM gained from three major advantages: a several year headstart, nearly worldwide roaming, and greater economies of scale. All digital technologies, of course, were benefited equally by the relentless increases in silicon integration, as predicted by Moore’s Law.

Today in the U.S. after about a decade of digital service and considerable consolidation of wireless service providers, CDMA users exceed NA-TDMA users by nearly two to one, with the gap growing. Of the three major nationwide carriers two, Verizon and Sprint use CDMA, while the third, Cingular, serves a mixed population with either GSM or NA-TDMA. To improve efficiency of operations, Cingular is converting the NA-TDMA users over to GSM, thus further shrinking the former base. A similar scenario is playing out in Japan. There the largest carrier, NTT-Doicom, originally developed a variant of NA-TDMA called PDC, while the second carrier, KDDI chose CDMA. The user base of PDC is also shrinking for reasons involving third generation service which we examine next.

In the late nineties, European regulators began planning for third generation (3G) higher speed data service and again considering both spectrum allocations and technologies. After some debate the technological choice was Wideband CDMA (W-CDMA), a derivative of the American CDMA, which differs primarily in bandwidth spreading to 5 MHz, rather than 1.25 MHz, but also in other parameters and some system features. In addition the regulatory bodies in most EU countries chose to auction the 3G spectrum. This happening in the overenthusiastic late nineties, the auction bids grew to unparalleled levels, the 3G licenses for UK, Germany and Italy combined reaching over 100 billion Euros. With this much invested the incentive to field the infrastructure and produce handsets was considerable. Nevertheless, the process took nearly five years to mature the technology, different and in some ways more challenging than the original CDMA and requiring backward compatibility with GSM, a quite different technology. In the meantime, for those American, Korean and Japanese carriers who had employed CDMA for their initial digital offering, the transition to the higher speeds of 3G was much easier and began five years ago in an embodiment called CDMA2000. It seems thus that the tables have turned, with European carriers struggling with the transition while most American carriers are facing an easier technology evolution. Still today 3G systems, with data speeds ranging from the hundreds of kilobits/sec up to a few megabits/sec, have

3 CDMA Development Group
4 GSM Association
gained momentum, reaching a total subscriber base of 50 million users with a predicted doubling within a year. Since GSM is the predominant current digital technology and W-CDMA has been made backward compatible to it and hence the natural transition for GSM carriers, the number of W-CDMA users has recently surpassed the subscriber base of high speed CDMA2000. The unanswered question is whether the EU carriers are now converting to 3G because of a perceived demand for high speed data or to utilize the expensive newly acquired spectrum with the technology mandated by ETSI, and by the way with a technology which is considerably more efficient than GSM.

Another wideband signaling technology, which originated in broadcasting and was adopted for wireline DSL and local area wireless networks as well, has also been proven effective in cellular networks through extensive trials. This technology, Orthogonal frequency division multiple-access (OFDMA), spreads its signal by distributing it over many subcarriers, closely spaced in frequency and covering a wide spectral band like CDMA, providing relative immunity to multipath fading and interference thus gaining efficiency. In addition, it possesses other processing features which show promise for greater gains.

The PC and Internet Access

The histories of digital computing and of the Internet have been covered extensively by many authors and participants; we shall only touch lightly on the main points of their convergence. Digital computers in their most primitive forms date back to the nineteen forties, but well into the seventies they existed mostly as mainframes in research institutions and major businesses; even the mini-computer heyday of the sixties and seventies extended the user base only modestly. It took the stirrings of the large scale integration and microprocessor era to bring computing to the public: the hobbyist in the seventies, small businesses in the eighties and everyone in the nineties and beyond. Two of the first applications which defined the PC industry were word processing and the spreadsheet, the first to replace the typewriter with an infinitely more flexible tool, and the second to facilitate almost all numerical manipulation from the checkbook to scientific calculation. But as useful as these applications are, they no longer account for the primary consumer usage of the now almost ubiquitous PC. They have been surpassed by communication, entertainment and storage of content.

The PC as a communication device, replacing the teletype and later partially the Fax machine, has a long history. As early as the sixties individuals were able to employ very low speed dial-up data modems to access mainframe computers or even terminals at their offices or at some central facility. But it was not until the unleashing of the Internet with the creation of the World Wide Web and more recently powerful search engines, along with high speed data service by wireline and cable carriers, that all forms of communication from simple messages to extensive content of all types have elevated the PC to the status of essential home appliance.
The Internet grew out of the ARPANET, a now seemingly modest attempt in the early seventies to connect the computing powers through moderate speed data transfers among a small set of universities and industries, all research grantees, contractors or affiliates of the Defense Advanced Projects Agency (DARPA). It grew considerably in participants, both numerically and geographically, and capabilities as its operation was taken over by the National Science Foundation in the eighties and eventually it was unleashed from government control, with membership extended to the private sector and through Internet Service Providers to the general public. The current estimate of persons who have accessed the Internet is nearly one billion. In North America the penetration is just over two thirds and in Europe just over one third, while in Asia it is approaching ten percent. A growing percentage is connected through high speed DSL and cable, enabling the downloading of high content sources.

As a result, over the past 15 years, electronic mail (email) has become the primary medium of personal as well as business letter writing, far exceeding the paper mail service and faxes. It also has replaced much telephone voice calling, particularly across multiple time-zone distances. But two industries are even more threatened by the Internet as its speed and capabilities grow. The first, the conventional wireline telephone industry already battered by wireless cellular telephony, is now further threatened by “Voice over Internet Protocol” (VoIP), which replaces the dedicated circuit-switched phone line by packet-switched service over the Internet bypassing the long-distance carrier’s lines and even the local exchange if both ends of the conversation are Internet connected. Until fairly recently Internet telephony was of lower quality because it suffered from latency problems inherent in the variability of Internet routing. This has now been chiefly remedied by the laying of vast quantities of optical fiber nationwide as well as overseas. The other industry affected by digital technologies generally, but high speed Internet accessibility in particular, is entertainment, with recorded music already threatened and video not far behind. PC manufacturers are increasingly incorporating entertainment capabilities through embedded hardware and software.

As a transition to discussion of wireless services, we should note that PC’s now come in all sizes, from desktops to laptops (which now outsell desktops in the U.S.) to personal digital assistants (PDA’s) and even to cellphones with PDA capabilities. All incorporate speakers and microphones, and some have cameras for stills or video. As silicon integration continues to run its course, sizes and power consumption diminish and the smaller devices gain the power and features of their larger ancestors, in all but one all-important feature, the user interfaces: the input keyboard and, even more importantly, the output screen.

**The Enigma of Broadband Wireless**

It is generally accepted that the number of wireless telephone subscribers reached and exceeded the number of wireline subscribers in the year 2000 when there were 600 million of each. Today wireless phones exceed wireline by a factor of three. A logical question then is when will broadband wireless exceed broadband wireline, or will it ever?
Before answering, we need to define both the terms “Broadband” and “Wireless.” Broadband is relative and partially a misnomer. It really is used in place of “High Speed”, but of course the wider the band utilized the higher the speed supported and in high interference and fading environments higher speed requires wider bandwidth. “Broadband” when applied to wireless refers today to several hundred Kilobits/sec. and above but soon it will refer to at least a few Megabits/sec.

Wireless on the other hand can have multiple meanings and refer to a variety of services and devices. Thus far we have considered mostly cellular networks, known also as wide area networks (WAN’s) and occasionally as metropolitan area networks (MAN’s). But there are two other categories of wireless: local area networks (LAN’s) implemented mostly by the IEEE 802.11 standards, commonly known as “WiFi” and personal area networks (PAN’s) implemented using the “Bluetooth” standard. PAN’s typically cover very short ranges, below 10 meters and serve mostly to reduce unsightly and pervasive cables; WiFi LAN’s with ranges of 100 meters or more serve well within the home or the enterprise and typically replace the wired “Ethernets.” Their usage has greatly increased with the inclusion of WiFi modems in many laptops and the establishment of WiFi “Access Points” (Base Stations) in coffee shops, airports, hotels, etc. Both PAN’s and LAN’s operate in Unlicensed Bands, usually around 2.4 GHz. To date, with the exception of a few extended range (few kilometer) access points employing 802.11 technology, all WAN’s employ licensed cellular bands. Unlike cellular WAN’s whose development and implementation is largely controlled by wireless carrier decisions, LAN and PAN developments have been driven by manufacturers marketing directly to consumers. LAN’s in particular have received a major boost by the inclusion of the modem capabilities in the PC microprocessors, and hence practically offered free to the consumer. Certain manufacturers are attempting to extend this success to WAN’s with a new technology standard IEEE 802.16e, which is already being marketed as WiMAX. Whether it would be offered in a licensed or unlicensed spectrum is as yet unspecified, nor are the costs and benefits compared to cellular well understood, especially given the massive expenditures in 3G infrastructure already invested by Verizon, Sprint, Vodafone, and others. Meanwhile some large cities, such as Philadelphia, Portland and the Bay Area are viewing this prospective new offering as a means of providing broadband service to the poorest third of their inhabitants who are not currently Internet connected. Time and economics will determine the feasibility of this plan. This also raises the question of whether such service needs to provide for terminal mobility or merely operate in stationary (fixed) locations. Early versions of the 802.16 standard addressed fixed wireless service. However, 802.16e is specifically designed for mobile operation, which is more demanding and costly.

Having thus defined the multi-faceted nature of what may be considered Broadband Wireless, we should be prepared to address the basic question of wireline-to-wireless replacement. For this, we need only consider WAN’s, since short-range wireless LAN’s are merely the data version of the cordless phone, a convenient extension within the home or office of the wired network. But we need to explore further the nature of the service and of the user’s terminal. There are three overlapping levels of service: fixed,
portable, and mobile, with increasing order of implementation complexity and cost and with decreasing range. Fixed service has the potential advantage of a high gain antenna and hence greater range, but it can only be economically justified in locations broadband DSL or cable is not available, unless as in the initiatives just previously mentioned, the costs of infrastructure and service are subsidized by governments. The argument for portable service is more compelling, since being able to access messages, information and even entertainment wherever located and whenever desired is of indisputable value. Full mobility, referring to broadband usage while in motion at even high automotive or airplane speeds, may be less essential. As we know, terminals come in all sizes: from desktops to laptops to PDA’s to ordinary cellphones, with practically a continuum of sizes and shapes. One accelerating trend is that the digital processing and storage capabilities require ever less size, weight and power, so the terminal is becoming ever more portable. Already, laptops have practically all the capabilities of desktops and this trend is extending downward to PDA’s. With the size of a notebook and the weight of at most a few pounds, terminals are becoming easily portable. Below the laptop, however, the limitation is the input-output, especially the screen size. Portable broadband wireless service then is becoming widely available in the U.S., Korea and Japan as at least two major carriers in each of these countries have or are in the process of upgrading base stations in metropolitan areas nationwide to support broadband CDMA systems. The evolution to full mobility (which chiefly requires handoff among base stations) is also underway. It should also be recognized that portable service can be partially provided by paid subscription to WiFi connectivity to “Hotspot” access points present in some coffee shops, airports and hotels. The competition is through economics; pricing in the U.S. for full wireless broadband service through cellular WAN’s is competitive with “Hotspot” service and much more widely usable.

Passing from the prospective and hypothetical to actual service offerings and marketing strategies, currently service providers throughout the Americas, Asia and Europe have installed infrastructure for broadband wireless data networks with base station throughput speeds in the megabits/sec. In North America and South Korea and partly in Japan, CDMA2000 (EV-DO), the high speed evolution of the earlier U.S. developed CDMA, and hence backward compatible to it, has predominated and gained about 20 million subscribers in the three years since its introduction [5]. European wireless carriers, following the lead of the largest Japanese carrier are implementing W-CDMA. This so-called 3GSM wideband service is backward compatible to GSM to capitalize on the enormous (1.6 billion) user base of GSM. The relative immaturity of W-CDMA, coupled with the problem of backward compatibility to a disparate technology, has slowed its introduction until this year. Presently though manufacturers are predicting sales of 70 million such terminals by the end of 2005 [6]. Another driver for such handheld terminals is the fact that in Asia and even Europe the penetration of the desktop or laptop PC is much less than in North America; hence the handheld, even with reduced capabilities, is for many the only device for Internet access. All told then there should be nearly 100 million broadband wireless enabled terminals by early next year, about 5% of the worldwide wireless total.

5. airvananet.com: solutions - EV-DO Snapshot
The key question remains what will these terminals and handsets be used for? Judging from marketing strategy and cultural differences between continents, target user populations may differ widely. The first U.S. carrier to offer high speed service aimed it directly at the business and professional user, offering a modem on a card for the laptop “road warrior”. Although a few PDA-size handholds are now available with the same technology, these have not been aggressively targeted to a large consumer market and their price consequently has been relatively high. Other less high-speed applications have been the consumer focus in North America. The opposite approach seems to be underway in Europe where 3GSM handsets are being offered at very low costs to “seed” the market. The real issue is not the technology used or its capabilities but the applications that users may want. And herein resides the enigma. Most of the applications of cellphones, even the most advanced ones, have not required or used broadband speeds and some have not even needed network connectivity. Of course, the overwhelming majority of cellphones are used only for voice conversations from local to long distances, for which there seems to be an insatiable human hunger. At about 8 Kbits/sec. compressed speech does not utilize high speed, though as we have repeatedly said, wideband signal transmission for each user greatly improves quality and efficiency. E-mail messages require even less speed though low latency is desirable. Until recently, the feature most in demand, as well as the most lucrative for carriers, has been the downloading of “ring tones.” One-time downloading of games and other pastimes, also lucrative, have equally not demanded high speed. Certainly, web browsing and real-time video transmission does demand broadband, particularly in the forward direction. Two-way video conversations might further load broadband wireless but this service offering has not been particularly successful via any medium. What are being heavily marketed are phones with built-in cameras and more recently high quality audio, neither of which requires wireless connectivity. Position location is of course a space-borne wireless technology, but one that is mostly independent of the cellular network other than for short control messages. A high-speed service soon to be offered will be television and radio broadcasts to cellphones or handheld terminals, but these will be transmitted on disparate spectrum independent of the multiple-access network.

Summarizing, the transmission of wideband signals, as generated by CDMA or OFDMA is extremely beneficial compared to GSM and other frequency- and time-division multiple access technologies. As broadband, meaning high-speed, transmission capabilities are added to these wideband signaling systems, the professional and business community will benefit through the ability to perform “desktop” functions anywhere and anytime, with terminals that can support adequate input-output resources. This represents a reasonably sized market in the low hundreds of millions, but not in the billions. The motivation of the European carriers is different. Since they have paid dearly for spectrum whose licenses require them to utilize newer technologies and since the efficiency of technologies such as W-CDMA is decidedly greater than GSM, it is much in their interest to convert as many of the 1.6 billion users as possible over to so-called 3GSM service. Low cost terminals, with possibly reduced features, will help the process and manufacturers will do their utmost to comply so as to prolong the massive volumes to which they have become accustomed. And finally in all regions, there is an unmistakable trend toward a single handheld device with the capability to perform multiple digital
functions, including desktop PC programs, audio and visual entertainment, position location and wireless connectivity to PAN, LAN and WAN networks. The Information Technology industry is counting on all sorts of as yet undiscovered applications to continue to create the demand for its products and services.