ANNEX 2

THE EMERGENCE OF THE SOFTWARE PHONE

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INTRODUCTION & EXECUTIVE SUMMARY

Software phones embody the functional properties of a thin-client network computer, a personal digital assistant, and a cellular phone. This revolutionary new class of personal communications appliances is emerging at the confluence of wireless communications and handheld computing. Of particular importance to mobile individuals and organizations, software phones would be capable of downloading a software implementation of a fully-functional, multi-band, multi-mode cellular telephone handset, thus overcoming the global roaming limitations imposed by today's multiple air interface standards. The term "software defined radio" (SDR) has been applied to this latter capability. In addition, software phone users would be able to download a much greater variety of software applications into appliances offering the full functionality of a wireless telephone handset and a hand-held computing device.

This four-part study has been carried out to assess the potential for software phones to emerge as the dominant design for future generations of wireless communications systems. Following an overview of the study in Section 1, the proliferation of wireless standards is reviewed in Section 2. Section 3 discusses the competition between traditional hardware-based approaches and innovative software-based solutions to the multi-standard problem. Section 3 also highlights several important lessons derived from recent studies of survival in rapidly changing industries. The five key findings of this report, presented in Section 4, provide a concise roadmap for the further development of the software phone:

1. Multi-mode and multi-band capabilities constitute one of six success strategies for 3G wireless standards.

2. Offering the most promising solution to the multi-standards problem, the software phone is expected to emerge as a dominant wireless communications platform in the next few years.

3. Software phones are gaining added momentum due to the fact that they unite two major industries.

4. Software phone concepts are being rapidly and widely acknowledged throughout the wireless communications and handheld computing industries.

5. Software phone concepts continue to forge more and more links throughout the wireless industry value chain.

Section 5 of the study summarizes separately the conclusions drawn from each of the four parts of the study. Potential beneficiaries of software phone technologies include component, terminal, and infrastructure vendors, service providers, and end users. Software phones can enable both established and new players to compete in markets that have previously been difficult to enter. Incumbent industry players have an opportunity to be important collaborators in the process of embracing SDR as a unifying technology. Without such collaboration, however, SDR could be exploited by new players to disrupt the status quo among leading handset manufacturers.

The above findings confirm the viability of SDR in target markets, but they also identify the need for increased involvement from key industry constituents to deliver the advantages of SDR to the wireless user.

This study was sponsored by the Software Defined Radio (SDR) Forum, formerly known as the Modular Multi-function Information Transfer System (MMITS) Forum, and carried out by a team from the Management of Technology (M.O.T.) Program at M.I.T.'s Sloan School of Management. The study was carried out at the Massachusetts Institute of Technology between September 1997 and May 1998, and combines extensive interviews of industry leaders with a detailed statistical analysis of factors most strongly influencing the evolution of wireless communications.

The M.O.T. program was pioneered at the Massachusetts Institute of Technology to provide mid-career managers with the advanced training needed to steer innovation in rapidly-changing technology-driven organizations. Team members John Ralston, Peter Bier, and Terry Hsiao combine over thirty years of experience in high-speed wireless and fiber-optics communications, cellular telephony, and digital migration of business processes. Faculty supervisor Fernando Suárez is a leader in the analysis of survival in rapidly changing industries.

Chartered in 1996 and formally incorporated in 1997, the SDR Forum is an open, non-profit organization dedicated to supporting the development, deployment and use of open architectures for advanced wireless systems. The Forum's primary purpose and objective is to encourage collaboration among an international group of equipment vendors, subsystems vendors, software developers, technology developers, communication service providers, research and engineering organizations, government users, regulators and other interested parties who share the common business interest of supporting the advancement of an interoperable modular technology base for multi-mode multi-band information transfer appliances. The Forum's primary activities are to promote national and international compatibility and interoperability, develop and/or promulgate uniform standards for such technology, conduct cooperative research, perform tests and prepare and disseminate informational materials.

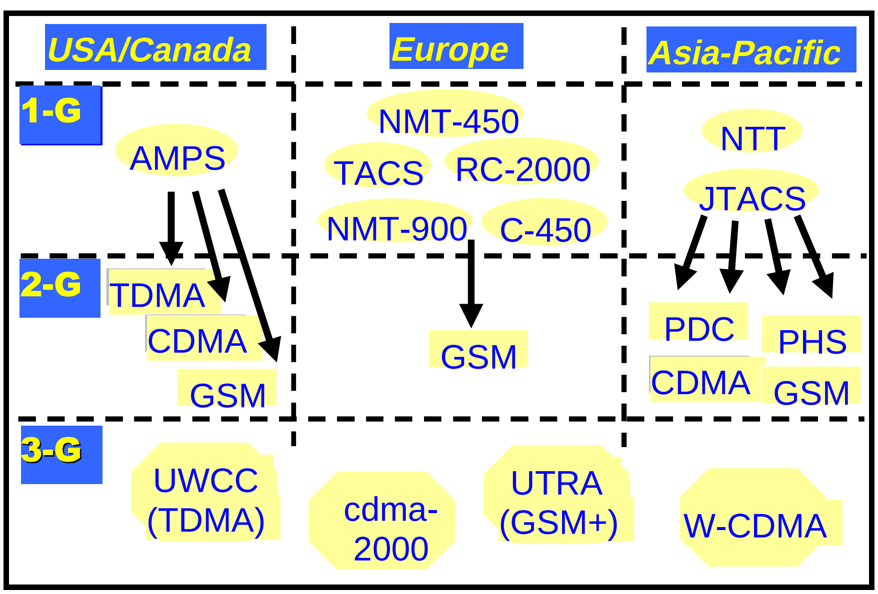
1 - Overview of the Study

Cellular telephone services, at the heart of today's wireless communications revolution, have evolved from a variety of early analog, or "1st-generation" standards, to today's more advanced digital, or "2nd-generation" standards (see Figure 1-1). In order to increase data rates and add more advanced digital services, 3rd-generation (3G) standards are now under development around the world; Figure 1-1 shows several contenders. The existence of so many competing techniques for addressing the same set of challenges is intriguing, and unique to personal communications.

Almost all other areas of information technology have quickly converged into one or two standards, with videotape formats and personal computer operating systems being two well-known examples. For the wireless communication market, this heterogeneity not only poses problems for highly mobile users attempting to roam between different types of networks with phones that work over only one air interface; it is also threatening to stunt market growth and delay the introduction of many lucrative new wireless services.

Under the pressure to develop low-cost consumer wireless communications products, two sharply divergent approaches have emerged to address the above standards proliferation problem. Following a more traditional hardware development route, one trend is to compress digital radio technology onto an ever decreasing number of silicon chips in order to achieve semiconductor industry economies of scale. The opposing effort seeks to transform radio from its present hardware-dominated status into a technology dominated by digital software, and known as software defined radio (SDR).

Figure 1-1. The evolution of analog (1st generation), digital (2nd generation), and enhanced digital (3rd generation) wireless standards.



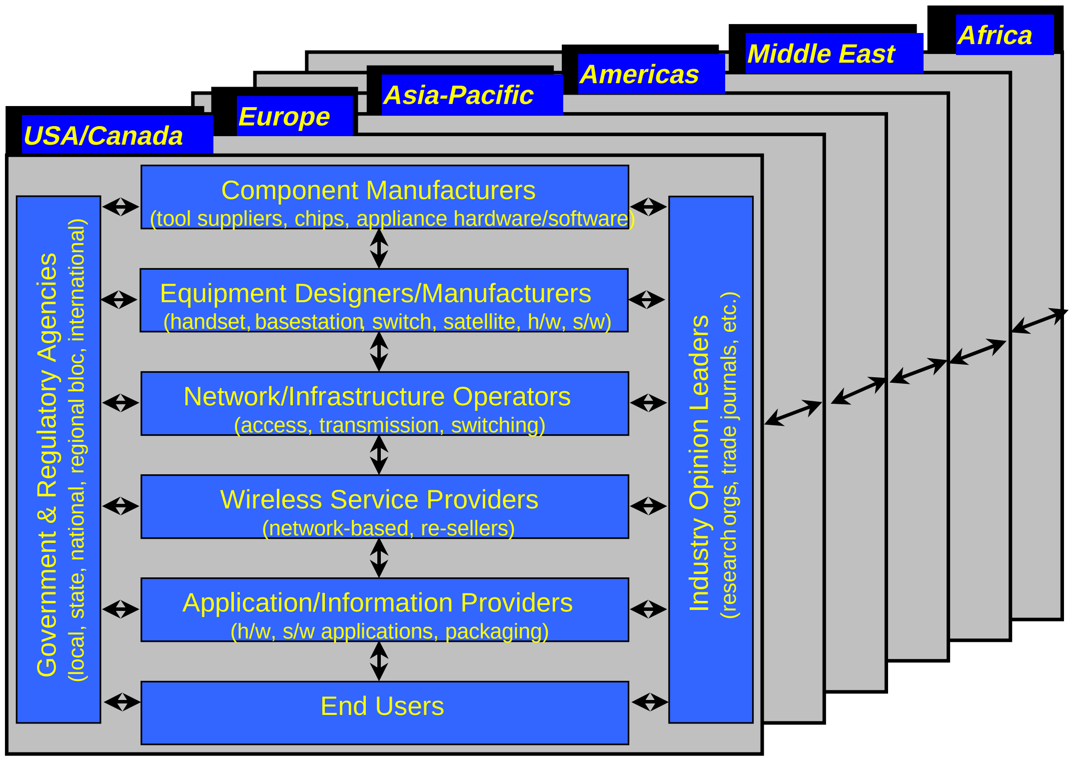
Note: A representative set of technologies is shown.

SDR could enable the development of wireless telephone handsets with the ability to reconfigure themselves, via real-time software downloads, to operate over any air interface. By migrating much of the radio functionality from hardware to software, such appliances could switch between air interfaces much as a computer switches between applications. Consumers, service providers, and hardware/software suppliers would all benefit from the powerful new hand-held information appliances and services that SDR would enable.

For the purposes of this report, such appliances are called "software phones". Emerging at the confluence of wireless communications and handheld computing, software phones embody the functional properties of a thin-client network computer, a personal digital assistant, and a cellular phone. Of key importance to the wireless communications industry, such appliances would be capable of downloading a software implementation of a fully-functional, multi-band, multi-mode handset in order to overcome the global roaming limitations imposed by today's multiplicity of air interface standards. Recent technological and market developments, however, suggest that the true potential of software phones may be realized in enabling downloads of a much greater variety of software applications into appliances offering the full functionality of a wireless telephone handset and a hand-held computing device.

This four-part study has been carried out to assess the strategic role of software phones in meeting future wireless communication needs. In particular, the potential for software phones to emerge as the dominant design for future generations of wireless communications systems has been examined in detail. Due to the complex and global nature of the wireless communications industry, the value chain shown in Figure 1-2 (on the following page) has been utilized as a framework for the study. Six key links are shown, from end users to component manufacturers. Two additional groups, government and regulatory agencies, together with industry opinion leaders, flank the outer edges of the value chain.

Figure 1-2. Wireless communications industry value chain.

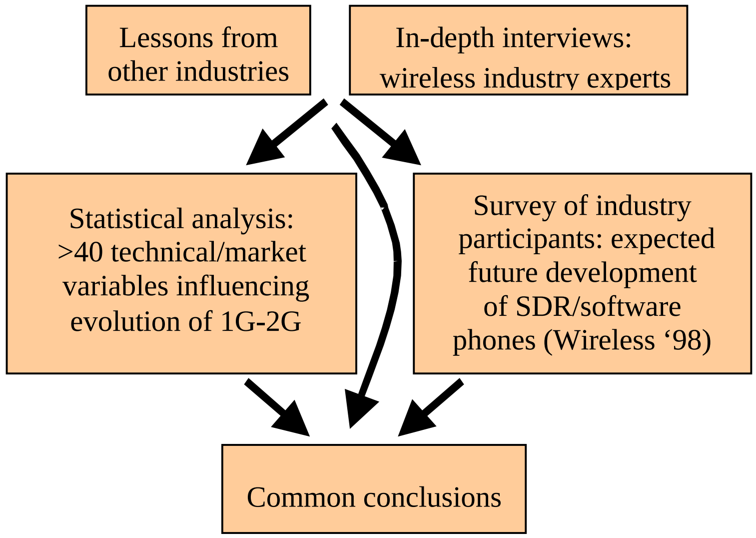


(Note: "Americas" refers collectively to Mexico, Central America, South America, and the Caribbean.)

While the elements of the value chain remain consistent between regions, the relative power wielded by each group and the relative strength of the relationships between the various groups differ significantly from region to region. Government and regulatory agencies in particular play significantly different roles steering the wireless industry throughout the world. There is a very large and growing number of organizations who offer products and services throughout the wireless industry. However, each of these different organizations may participate in more than one group within the value chain. Regional alliances also play a pivotal role in determining which standards and technologies ultimately emerge.

With the above value chain as a first foundation, software phone technologies have been evaluated in terms of their potential to emerge as the dominant design for future generations of wireless communications systems. Figure 1-3 presents an overview of the corresponding four-part study undertaken at M.I.T.

Figure 1-3. Overview of the four-part study.



Important and relevant lessons derived from recent studies of survival in rapidly changing industries were first reviewed. This part of the study drew its conclusions from current literature on technological innovation, the emergence of dominant designs, and the survival of firms in rapidly changing industries.

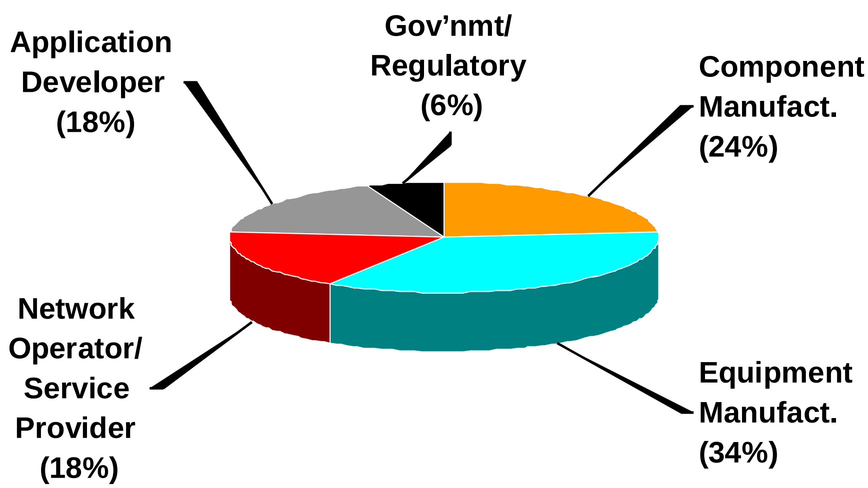
In-depth interviews were next carried out with industry experts in order to map out the most strategically important features on the wireless standards "battlefield" from the perspectives of a wide variety of players spanning the wireless industry value chain. The questions asked in these interviews were designed to determine the level of awareness of the software phone in the wireless industry and the likely receptivity of the wireless industry to such an innovative new wireless technology.

Third, the evolution of 1st- and 2nd-generation wireless standards was analyzed in detail, in order to identify and extrapolate potential success strategies for any proposed future wireless standards. The primary source of data for this study was EMC[1], the world's number one independent single-industry-focused supplier of market intelligence for the wireless industry. EMC provides continuously updated information and data, gathered from a global network of researchers. Data was collected for over 40 variables related to numbers of subscribers, subscriber market shares, regional adoption of analog and digital standards, handset and infrastructure equipment manufacturers, government support for the development of standards and technologies, technological performance, and rate of technological innovation. The above data was assembled on a quarterly basis covering the period 1983 to 1998 (first quarter), for all major regions shown in Figure 1-2. Extensive regression analyses (see Appendix 2) were carried out for the 1st-generation (analog) and 2nd-generation (digital) standards shown in Figure 1-1. By analyzing the growth in the number of subscribers for companies grouped around various wireless standards, it has been possible to identify factors influencing the eventual success or failure of each standard. This approach is similar to recent studies that build upon the tools of evolutionary biology to assess probabilities of failure for firms within an industry. The results have been used to assess the likelihood of the software phone emerging as the "dominant design" for 3G wireless connectivity.

Finally, wireless industry participants were invited to share their knowledge, expertise, and expectations concerning the possible future evolution of software phone products. Data was gathered at the CTIA **Wireless '98** Conference and Tradeshow in Atlanta, Georgia, to investigate the degree of market consensus as to the key design elements and rate of market penetration of software phones products. This annual CTIA event is the world's largest industry tradeshow for cellular/PCS products and services.

Figure 1-4 shows the breakdown of participants in the interview and survey components of the study, in terms of their corresponding membership within the wireless industry value chain (Figure 1-2). Participants were drawn more or less evenly from organizations representing the three most prominent geographical blocks shown in Figure 1-2: USA/Canada, Europe, and Asia-Pacific. More than 90 wireless industry professionals contributed to the study.

Figure 1-4. Breakdown of value chain representation in interview and survey components of study.



2 - The Proliferation of Wireless Standards

2.1 Introduction

The compelling need for a software phone is highlighted again and again by the chaos and confusion that arise in the wake of emergency events such as the Oklahoma City bombing and New York's World Trade Center bombing. Multiple civil government rescue forces – firefighters, police officers, and emergency medical personnel - arriving at the scene are unable to communicate with each other because their radio systems utilize incompatible "air interfaces". This confusion places lives at risk, and has driven government officials to begin exploring solutions to the communications interoperability problem. The same interoperability problems create even more dangerous communications situations for the military. In recent years, the various branches of the armed forces have procured incompatible radio systems, giving rise to problems during joint exercises involving multiple forces.

Out of the military's interoperability problem was born *Speakeasy*[2], an inter-branch military development program established to provide radios which, in the future, would allow troops from all branches to talk to each other, regardless of where they might see action. This goal would be accomplished using a new technology referred to as *software radio*[3], or *software defined radio* (SDR), which would implement most of the radio functions as software algorithms running on special purpose digital signal processors. General-purpose radios could then be built that would be capable of downloading these algorithms over the airwaves and reconfiguring themselves so as to talk to any other radio, regardless of its specific signal format. A very similar need has also emerged in the commercial wireless communications market.

The earliest commercial cellular telephone systems went into service in 1980 and 1981 in Japan and Scandinavia[4]. The 1980s and 1990s have seen rapid expansion of geographical coverage and subscriber populations in most parts of the world. So-called 1st-generation (analog) cellular networks began to be augmented or replaced by 2nd-generation (digital) technologies in the early 1990s. Digital wireless networks, in turn, have allowed a wide range of new communication products and services to be introduced[5], with much more to come in the near future. Pent-up consumer demand to move multi-media communications off of the desktop and to get rid of all the cables have made portable wireless communications one of the fastest growing industries today, with cellular and PCS telephone services leading the way. At the time of this writing, the international wireless community is in the midst of the process of developing and approving 3G wireless communications standards[6], designed to greatly increase the data rates that can be accessed via commercial wireless networks.

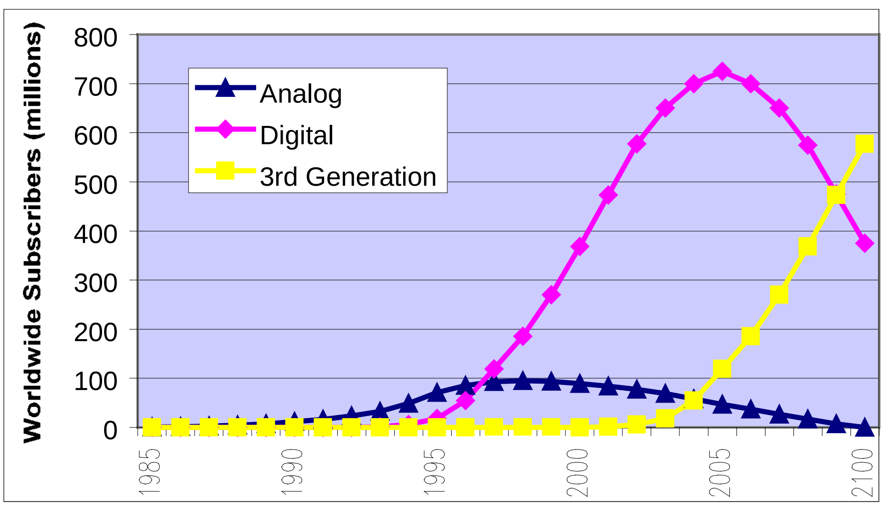
The recent proliferation of new wireless technologies and competing air interfaces has given North American customers the choice of one major analog service (AMPS) and three major digital protocols (TDMA, CDMA, and GSM). To make matters worse, as early wireless spectral allocations have become congested in the U.S., the above digital standards have had additional bandwidth assigned by the Federal Communications Commission (FCC) in different frequency bands (1900 MHz, as opposed to the initial 800 MHz bands). These newer 1900 MHz digital services have all been launched in North America under the name of PCS, in an attempt to distinguish them from the original 800 MHz digital cellular services; this marketing ploy has only added to the confusion suffered by millions of subscribers.

Internationally, competing protocols include those found in the U.S. market, the dominant European digital standard (GSM), and several additional digital and analog interfaces. Multi-band services have also been launched in many other regions of the world, but not necessarily using the same frequency allocations as in the U.S.

2.2 First, Second, and Third Generation Wireless Communications

Figure 2-1 reveals that digital cellular subscribers first surpassed analog subscribers in terms of worldwide number in late 1997. The number of analog subscribers in the world is expected to peak in 1998, and then dramatically decrease as the number of digital subscribers continues to swell. This behavior portrays digital cellular technologies and standards as "disruptive" to their analog predecessors in the cellular marketplace. Due to the much greater difference in performance, 3G wireless communications technologies are likely to prove even more disruptive, as a result of growing consumer familiarity with and demand for more flexible and higher speed wireless communications services.

Figure 2-1. Expected evolution of 1st-, 2nd-, and 3rd-generation wireless technologies. Figures through 2003 are taken from the EMC database. Numbers of subscribers beyond 2003 are projected.



2.2.1 First Generation Systems

Table 2-1 lists some aspects of analog wireless systems that have been deployed throughout the world.

Table 2-1. Representative analog cellular technologies currently deployed in various regions.

AMPS	Advanced Mobile Phone System. Developed by Bell Labs in the 1970s and first used commercially in the United States in 1983. It operates in the 800 MHz band and is currently the world's largest cellular standard.
C-450	Older cellular technology found mainly in Germany and Austria. Operates at 450 MHz. Developed by Siemens, C-450 was opened on a trial basis in September 1985 and fully opened in May 1986
N-AMPS	Narrowband Advanced Mobile Phone System. Developed by Motorola as an interim technology between analog and digital. It has some three times greater capacity than AMPS and operates in the 800 MHz range.
NMT-450	Nordic Mobile Telephones/450. Developed specially by Ericsson and Nokia to service the rugged terrain that characterizes the Nordic countries. Operates at 450 MHz.
NMT-900	Nordic Mobile Telephones/900. The 900 MHz upgrade to NMT 450 developed by the Nordic countries to accommodate higher capacities and handheld portables.
NTT	Nippon Telegraph and Telephone. The old Japanese analog standard. A high-capacity version is called HICAP.
RC-2000	Radiocom 2000. French system launched November 1985
TACS	Total Access Communications System, similar to AMPS, but operating in the European 900 MHz analog cellular frequency range. First used in the United Kingdom in 1985. Also used in Japan, where it is called J-TACs.

2.2.2 Second Generation Systems

The most widespread second-generation standards are: the European standard, GSM; and two North American standards, IS-136, a time division multiple access (TDMA) technique, and IS-95, a code division multiple access (CDMA) technique. The GSM standard, which has been adopted in more than 100 countries, specifies a complete wide-area communications system. The other two standards specify only the communications between mobile telephones and base stations. A separate standard, IS-41, governs communications between mobile switching centers and other infrastructure elements in the United States. A TDMA technique developed in Japan, and known as Personal Digital Cellular (PDC), has also proven to be highly successful, although in a much more geographically limited region. Each of the second-generation systems has distinct features and limitations, but none was designed specifically with the problems of large, complex national and international organizations in mind.

Table 2-2 (on the following page) lists some aspects of digital wireless systems that have been deployed throughout the world.

Table 2-2. Representative digital cellular technologies currently deployed in various regions.

CDMA	Code Division Multiple Access. IS-95 standard implemented in North America and heavily promoted by Qualcomm. Characterized by high capacity and small cell radius. It uses the same frequency bands as AMPS and supports AMPS operation, employing spread-spectrum technology and a special coding scheme. It was adopted by the Telecommunications Industry Association (TIA) in 1993. The first CDMA-based networks became operational in 1995.
DCS 1800	Digital Cordless Standard. Name originally given in Europe for GSM operating in the newer 1800 MHz spectral bands. Dual-mode phones allow access to both 900 MHz and 1800 MHz GSM networks. Tri-mode phones will soon allow “world-phone” service over networks using any of the three international GSM frequency bands (900, 1800, and 1900 MHz).
DECT	This started as Ericsson's CT-3, but developed into ETSI's Digital European Cordless Standard. It is intended to be a far more flexible standard than the CT-2 standard, in that it has more RF channels (10 RF carriers x 12 duplex bearers per carrier = 120 duplex voice channels). It also has a better multi-media performance since 32kbit/s bearers can be concatenated. Ericsson is developing a dual GSM/DECT handset that will be piloted by Deutsche Telekom.
GSM	Global System for Mobile Communications. The first European digital standard, developed to establish cellular compatibility throughout Europe. Its success has spread to all parts of the world and over 100 GSM networks are now operational at 900, 1800, and 1900 MHz.
PCS (generic)	Personal Communications Service. The PCS frequency band is 1850 to 1990 MHz, which encompasses a wide range of new digital cellular services based on GSM, TDMA, and CDMA. Single-band GSM 900 phones cannot be used on PCS networks. PCS networks are already operating throughout the USA.
PDC	Pacific (or Personal) Digital Cellular is a TDMA-based Japanese standard operating in the 800 and 1500 MHz bands.
PHS	Personal Handyphone System. A Japanese system that combines cordless and cellular telephone functionality to offer high-speed data services and superb voice clarity. PHS operates in a 1900 MHz band.
TDMA (IS-54, IS-136)	Digital AMPS. An upgrade to the analog AMPS. Designed to address the problem of using existing channels more efficiently, DAMPS (IS-54) employs the same 30 kHz channel spacing and frequency bands (824-849 and 869-894 MHz) as AMPS. By using TDMA instead of FDMA, IS-54 increases the number of users from 1 to 3 per channel (up to 10 with enhanced TDMA). An AMPS/D-AMPS infrastructure can support use of either analog AMPS phone or digital D-AMPS phones. The Federal Communications Commission mandated that digital cellular in the U.S. must act in a dual-mode capacity with analog.

2.2.3 Entry of Third Generation Systems

The commercial success of second-generation wireless telephone systems has stimulated widespread interest in enhancing their capabilities to meet public expectations for advanced information services. The original concept for 3G wireless systems emerged from an International Telecommunications Union (ITU) initiative known as the future public land mobile telecommunication system (FPLMTS). Over the past decade, the ITU advanced the concept of a wireless system that would encompass technical capabilities a clear step above those of second-generation cellular systems. The third generation cellular standards have three main sets of criteria: a vehicular data rate of 144 Kbits per second, a pedestrian data rate of 384 Kbits per second and a stationary data rate of 2 Mbits per second. With the new high-speed two-way connectivity, wireless carriers can add a new weapon to their arsenal, positioning them to further compete with wireline carriers.

The current name for the FPLMTS system is International Mobile Telecommunications-2000 (IMT-2000). The number refers to an early target date for implementing the new technology and also the frequency band (around 2000 MHz) in which it would be deployed. As envisioned in the IMT-2000 project, the third-generation wireless system would have a worldwide common radio interface and network. It would support higher data rates than do second-generation systems yet be less expensive. It would also advance other aspects of wireless communications by reducing equipment size, extending battery life, and improving ease of operation. In addition, the system would support the services required in developing as well as developed nations. At the time of this writing, however, it appears that the IMT-2000 process will not lead to a single 3G standard, and even the ITU has begun to speak of an interoperable “family of standards”. Table 2-3 (on the following pages) lists candidate technologies that have be submitted to the ITU for consideration for IMT-2000 third generation standardization. These Radio Transmission Technologies (RTTs) were those filed with the ITU as of June 30, 1998 the cutoff date for such proposals. Further information may be found at the ITU web site for IMT-2000 at http://www.itu.int/imt.

Among related developments, interest in "nomadicity" is growing within the Internet community in the United States. As originally conceived, the national information infrastructure (NII) placed little emphasis on the wireless delivery of information to mobile users (Computer Science and Telecommunications Board, 1994). But with the growth in demand for Internet services, reflected by the transition to private suppliers, providers are seeking to leverage Internet technology either directly or as part of heterogeneous networks. Plans are being made to accommodate nomads (i.e., mobile users) who draw on a variety of communications, computing, and information systems simultaneously, a concept that will require attention by multiple industries to issues such as security, interoperability, and synchronization within and between systems.

Although it is clear that many new wireless communications technologies will emerge in the 2002 - 2005 time frame, it is not clear when and how they will be commercialized. The robust evolution of second-generation systems will limit commercial incentives to introduce a new generation of systems. It is possible that advances in second-generation systems will meet future demand for mobile telephone services and that a demonstrated demand for high-bit-rate data services will be necessary to stimulate the commercial deployment of third-generation technology.

High-speed data capable third generation systems will offer a broad bandwidth pipeline in addition to voice and low speed data, providing the full range of telecommunications services. As a result, it is expected that there will be a future crossover from wireline development to wireless infrastructure. It is important to consider that third generation systems are still a minimum of three or four years away from possible deployment, however.

Several powerful market forces have begun to accelerate international progress towards introducing higher speed wireless access. Explosive growth in the demand for Internet-like services, coupled with the growing need for portability and roaming, have created serious demand for such wireless access. Major expansions of fiber-optic backbones have provided a connecting infrastructure with which to link wireless urban networks. The prohibitive cost and continuing immaturity of fiber-to-the-customer solutions have made wireless the technology of choice for flexible high-speed network connectivity. However, this window of opportunity may become substantially smaller after 2002 when new satellite services such as Teledesic are launched. It is very likely that some combination of 3G wireless standards and new satellite networks will ultimately shape the Internet's future.

The Internet is growing at a phenomenal rate, and the demand for graphics-laden and multi-media information is expected to continue to increase across the globe. Optimistic predictions put the Internet at a billion users by 2001. Yet there is a big barrier for the multi-media World Wide Web (WWW) and other multi-media communications: the shortage of bandwidth available in today's global information infrastructure. Without bandwidth, Internet users have been unable to use real time audio and video capabilities, stunting the widespread use of these new “killer applications” that are expected to drive a new Internet boom.

This demand has provided a window of opportunity for wireless carriers and 3G cellular standards to enter into the bandwidth provision market. Wireline solutions to the bandwidth shortage still seem far from realization. Enter dedicated 3G wireless cellular services. Using a 3G service provider, multi-media users will be guaranteed access anywhere within the service provider's coverage area. Once a network is upgraded, the need for a personal wire to the curb may be reduced. Instead, a 3G wireless terminal could solve the so-called “last mile” problem. As a consumer solution, the delivery of 144 Kbits significantly improves the real time capabilities for audio and video. At 2 Mbits, the end-user has access to substantially higher quality video capabilities.

Table 2-3. Representative terrestrial and satellite candidate technologies for 3rd Generation

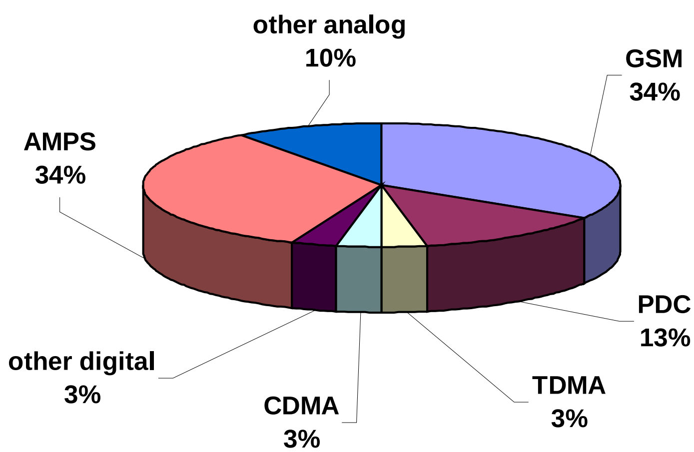
IMT-2000 Radio Transmission Technology (RTT) Proposals as submitted to the ITU in June 1998

	PROPOSAL	DESCRIPTION	SOURCE
USA	UWC-136	Universal Wireless Communications	USA TIA TR45.3
USA	cdma2000	Wideband CDMA (IS-95)	USA TIA TR45.5
USA	WIMS	Wireless Multimedia & Messaging Services	USA TIA TR46.1
USA	W-CDMA	Wideband CDMA	USA TIA TR46.1
USA	NA: W-CDMA	North American: Wideband CDMA	USA T1P1-ATIS
EUROPE	UTRA: W-CDMA	UMTS Terrestrial Radio Access: Wideband CDMA	ETSI SMG2
EUROPE	DECT	Digital Enhanced Cordless Telecommunications	ETSI Project (EP) DECT
EUROPE	SW-CDMA	Satellite wideband CDMA	ESA
EUROPE	SW-CTDMA	Satellite wideband hybrid CDMA/TDMA	ESA
ASIA	W-CDMA	Wideband CDMA	Japan ARIB
ASIA	CDMA I	Multiband synchronous DS-CDMA	S. Korea TTA
ASIA	CDMA II	Asynchronous DS-CDMA	S. Korea TTA
ASIA	SAT-CDMA	49 LEO satellites in 7 planes at 2000 km	S. Korea TTA
ASIA	TD-SCDMA	Time-Division Synchronous DS-CDMA	China Academy of Telecommunication Technology (CATT)
	ICO RTT	10 MEO satellites in 2 planes at 10390 km	ICO Global Communications
	Horizons	Horizons satellite system	Inmarsat

2.3 The Shift Across the Wireless Generations

Figure 2-2 shows the worldwide market shares (as percentages of the total number of subscribers) of the major analog and digital standards, or groups of standards, as of the end of 1997.

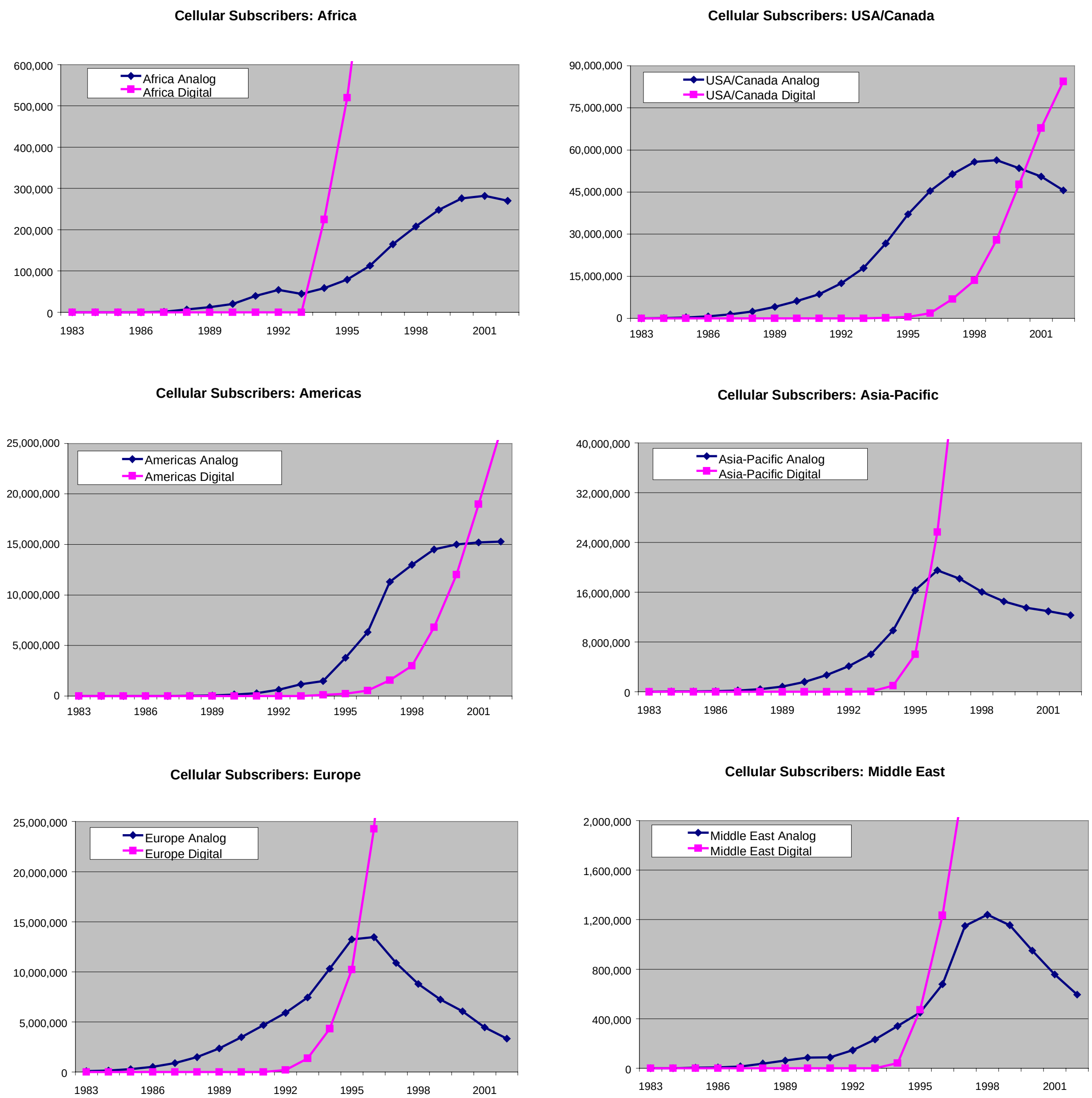
Figure 2-2. World market share for major wireless standards, December 1997.



(Source: EMC database)

As of December, 1997, there were a total of 212 million cellular telephone subscribers worldwide, 93 million using analog services and 119 million using digital services. Figure 2-3 highlights the degree to which the rate of displacement of 1st-generation cellular technologies by 2nd-generation technologies has varied throughout the major international regions. The transition to digital has been the slowest in North America, and has been characterized by the evolution from a single analog standard to several competing digital standards; in the first quarter of 1998, North American cellular services are still 80% analog. Europe, on the other hand, underwent a much faster transition from many competing analog standards to a single digital standard; in the first quarter of 1998, European cellular services are already 90% digital. The evolutionary trends and subscription rates for digital wireless subscribers have not slowed.

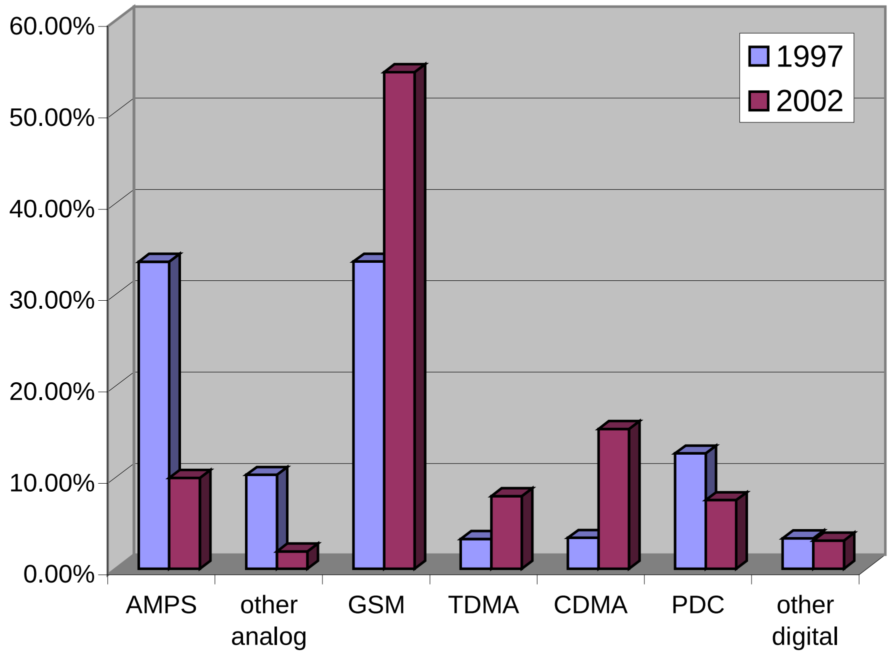
Figure 2-3. Cellular subscribers by world region, 1983 – 2002.



(Source: EMC Database)

Figure 2-4 presents current growth forecasts for the major analog and digital standards, or groups of standards, between the end of 1997 and the end of 2002. Market shares are given in terms of percentages of the total number of subscribers worldwide.

Figure 2-4. Comparison of world market shares for 1997 (actual) and 2002 (forecast).



(Source: EMC database.)

Clear trends have emerged in the worldwide implementation of the various standards discussed above. Figure 2-5 shows the market shares held by each of the major standards in each of the six major world regions at the end of 1997, along with projected figures for the end of 2002. It is clear that whereas Europe has focussed primarily on a single standard – GSM - most of the rest of the world has experienced a standards battle involving TDMA/PDC, CDMA, and GSM.

Figure 2-5. Deployed cellular technologies: 1997 and 2002 (% of subscribers in market).

USA/Canada

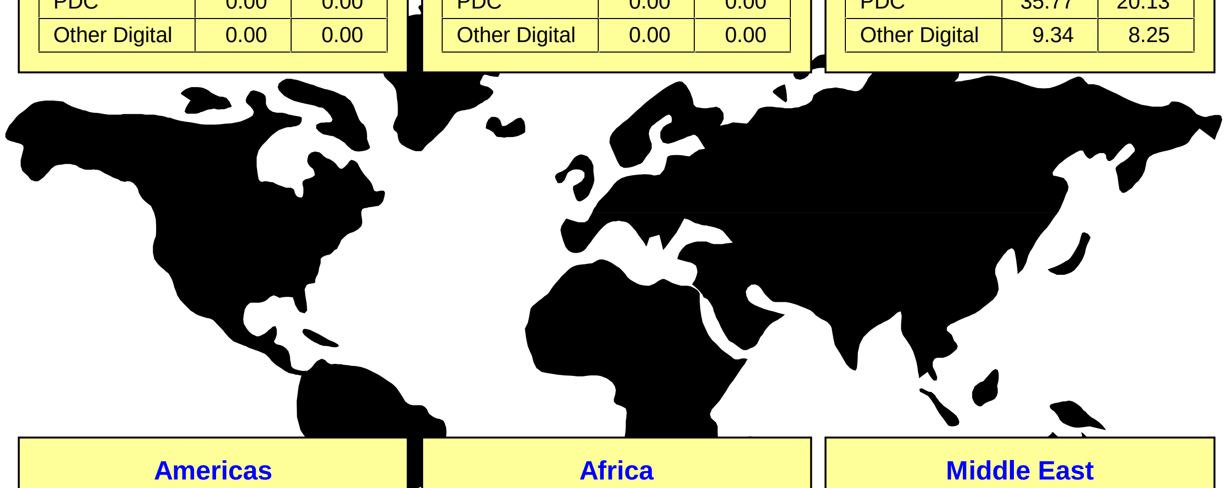
	1997	2002
AMPS	88.30	35.07
Other Analog	0.00	0.00
GSM	2.27	16.46
TDMA	6.69	23.76
CDMA	2.74	24.71
PDC	0.00	0.00
Other Digital	0.00	0.00

Europe

	1997	2002
AMPS	0.11	0.25
Other Analog	17.78	1.28
GSM	81.91	97.34
TDMA	0.20	0.97
CDMA	0.00	0.16
PDC	0.00	0.00
Other Digital	0.00	0.00

Asia-Pacific

	1997	2002
AMPS	9.97	1.23
Other Analog	14.33	3.82
GSM	22.73	42.06
TDMA	0.49	1.01
CDMA	7.36	23.50
PDC	35.77	20.13
Other Digital	9.34	8.25



Americas

	1997	2002
AMPS	87.98	36.78
Other Analog	0.00	0.00
GSM	0.21	7.21
TDMA	11.42	34.38
CDMA	0.39	21.63
PDC	0.00	0.00
Other Digital	0.00	0.00

Africa

	1997	2002
AMPS	2.83	1.77
Other Analog	5.60	2.02
GSM	91.33	95.74
TDMA	0.09	0.07
CDMA	0.15	0.41
PDC	0.00	0.00
Other Digital	0.00	0.00

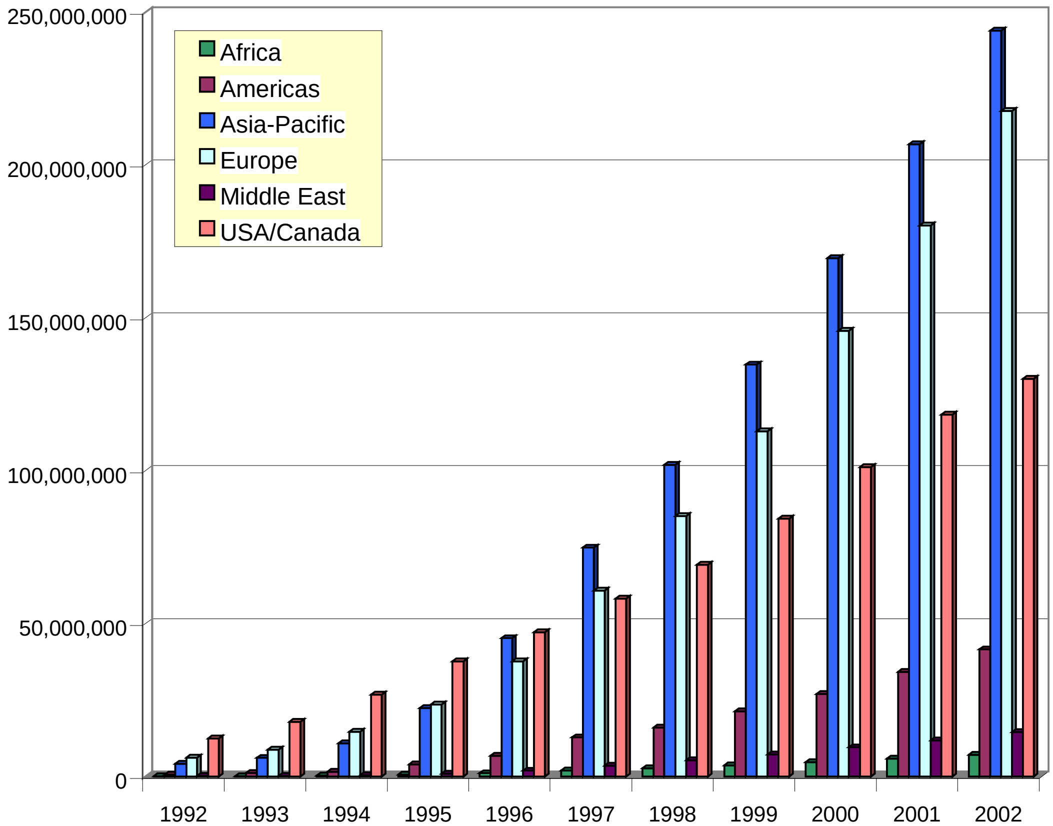
Middle East

	1997	2002
AMPS	28.70	3.40
Other Analog	3.93	0.69
GSM	38.34	70.72
TDMA	29.03	15.11
CDMA	0.00	10.07
PDC	0.00	0.00
Other Digital	0.00	0.00

(Source: EMC database)

Figure 2-6 depicts the predicted worldwide growth in cellular subscribers over the period 1992-2002. It is apparent in the future that the Asia-Pacific region will soon grow to outnumber all other regions in market size, and may begin to play a much more dominant role in defining the wireless industry.

Figure 2-6. World cellular subscribers by region, 1992-2002.



(Source: EMC database)

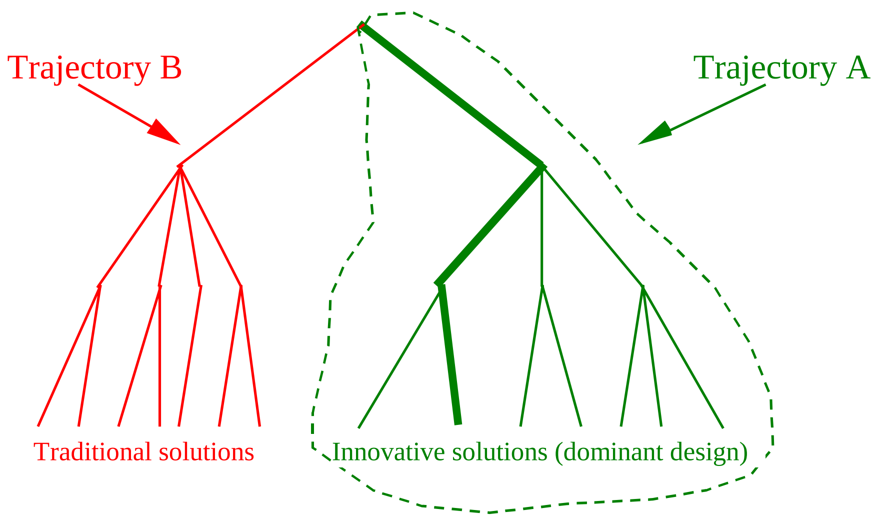
3 - Traditional vs. Innovative Solutions

3.1 Introduction

Two competing solutions are being pursued in the cellular communications industry in an attempt to remedy the proliferation of wireless standards, the extreme cases being an all-silicon solution and an all-software solution. Most industry specialists who were interviewed during the course of this study conceded that the collision of the cellular telephony and personal computer industries favors the eventual emergence of the software phone as the dominant design for a broad variety of "hybrid" handheld products. However, the severe constraints on size, power consumption, and cost imposed by consumer handheld appliance markets still pose several technical challenges, and substantial hardware solutions will be required in order to realize the full potential of the software phone.

Which of these two alternatives emerges as the "dominant design" will be determined by the interplay between technical and market choices. The design hierarchies approach shown in Figure 3-1 is a useful means of representing the evolution of a dominant design.

Figure 3-1. Emergence of a Dominant Design.



Within an industry, each choice of a core technical concept establishes a path of technical progress, or a technical trajectory; there are two such trajectories shown above. The subsequent series of technical decisions about the product's design evolution are constrained by both prior technical choices and by the parallel evolution of customer preferences. A dominant design which emerges as the final outcome need not represent a radical change, and is indeed more likely to result from the creative synthesis of available component technologies and the existing knowledge about customer preferences into innovative new product architectures. The dominant design may not be optimized in a broader context, but rather a design that becomes an effective standard.

In light of these latter remarks, it is critical to examine customer and market needs that provide compelling evidence for pursuing software phone technologies. The evolution of the wireless industry to date has been very similar to the case depicted in Figure 3-1. Analog and digital paths have been established, and both of these have subsequently split into several different air-interface standards operating within several different frequency ranges. Several well-established trajectories have emerged to become today's dominant air-interface standards, but the demand for new high-speed wireless services is poised to trigger further evolutionary steps. Software phones will have the greatest impact on the wireless industry if they are viewed as a dominant design element that enables the creative synthesis of existing wireless technologies and standards, rather than as a radical leap to a new trajectory.

3.2 Lessons from Other Industries

The study of technological innovation has assumed great importance for today's rapidly advancing technology-based industries. Software phones represent an innovative new technology that has the potential to disrupt the market for existing wireless communications platforms (i.e. the traditional approach), and to become either a new dominant design or to deliver elements of a dominant design.

3.2.1 Emergence of Dominant Designs

A dominant design in a product class is, by definition, the design that wins the allegiance of the marketplace. Competitors must adhere to such a design if they want to command a significant market share. The dominant design may take the form of a new product or a well-defined set of product features. Often, the dominant design is not a major innovation, but rather a design that synthesizes individual innovations introduced independently in prior product variants. For example, the IBM PC format quickly became the dominant design in its market, even though it contained little in the way of breakthrough technology. It did, on the other hand, integrate into one product many familiar elements that had individually proven their value to computer users. A dominant design typically satisfies the requirements of many customer segments, although not to the same extent as designs customized for each individual segment. The dominant design typically does not achieve the most extreme technical performance available in its product class. Its performance is a compromise between technical possibilities and market choices.

The emergence of a dominant design is also determined by the interplay between technical and market choices as a function of time. Many factors other than technology and design superiority come into play[7], including:

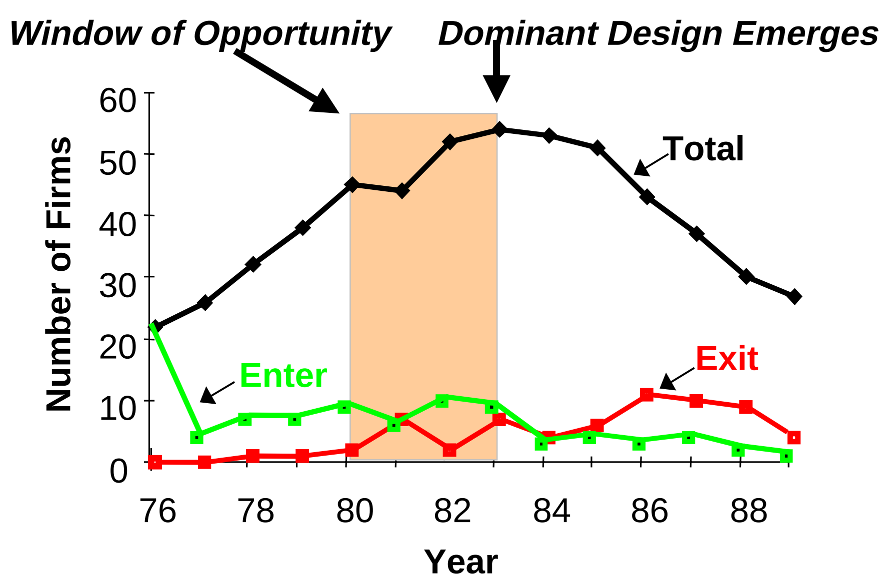
- (i) Collateral assets[8], such as market channels, brand image, or customer switching costs.
- (ii) Network externalities in the market, such as additional infrastructure that must be installed before an innovation can be widely adopted.
- (iii) Strategic maneuvering at the firm level, a well-known example being JVC (VHS) versus Sony (Betamax) in the battle for videocassette recorder standards dominance.
- (iv) Communication between producers and users.
- (v) Government regulation and/or purchasing power.

The above five factors will all be important to the future development of software phone technologies.

The emergence of dominant product designs has been investigated to date predominantly as a factor affecting the survival of firms within an industry. In particular, the emergence of a dominant product design has been revealed as a watershed event that drastically reduces the probabilities of success for subsequent entrants[9,10,11,12,13]. A clear distinction has been made between competence-destroying innovations (typically introduced by new firms, and leading to increased market turbulence) and competence-enhancing innovations (typically introduced by existing firms and leading to decreased market turbulence[14]). The tools of population ecology have also been employed to identify those forces that most powerfully affect the probabilities of survival for firms confronted with technological innovation [15,16]. These latter tools have been exploited to analyze the survival statistics of high-technology firms within turbulent industries[9].

The following two figures illustrate the impact of dominant design emergence within rapidly changing industries. In Figure 3-2, the period preceding the emergence of a dominant design is shown to be characterized by an increasing number of market entrants, while the period immediately following the emergence of a dominant design is typically marked by many unsuccessful competitors being forced to exit the industry. One important finding is that there is very often a "window of opportunity" in the industry just prior to the emergence of the dominant design, during which entry is particularly advantageous.

Figure 3-2. Typical influence of dominant design emergence on the number of firms in an industry.

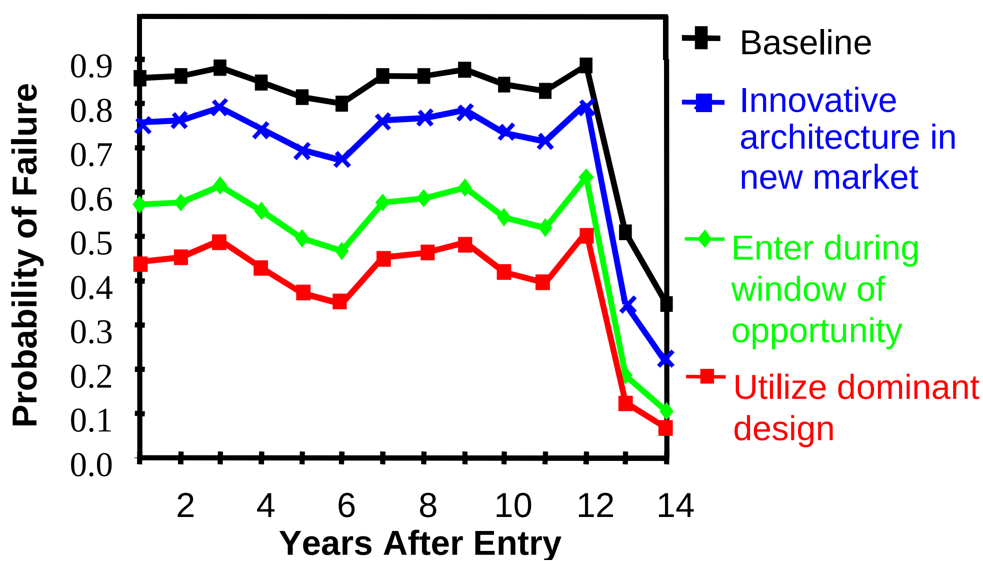


(Source: reference 13)

The second insight relates to the risk of betting on new technologies, versus betting on new markets. It has been found that firms whose entry strategies involved using proven component technologies in innovative product architectures that facilitated the emergence of new market segments had significantly higher probabilities of survival than did firms that entered established market segments with new component technologies that offered better performance. In other words, entry strategies that entail *market* risk (entering an emerging market with proven component technology) may be less risky than strategies that entail *technological* risk (entering an established market with new, higher-performance component technology)[17]. This risk does not appear to be appreciated by many potential entrants into the market for advanced wireless communications products and services, where SDR must attack both existing and emerging markets.

Figure 3-3 shows how, in addition to pursuing what would emerge as the dominant design, choosing an appropriate combination of innovation and entry market significantly reduced disk drive firms' probability of failure. Architectural innovators entering new markets presented a much lower hazard than did baseline firms, who continued to promote existing product designs. For the example shown in Figure 3-3, the probability of failure for the baseline firm during its sixth year of business was much higher than it was for a firm that was an architectural innovator and entered into a new market.

Figure 3-3. Typical impact of dominant design on a firm's probability of failure.



(Source: reference 13)

The main hypotheses supported by previous studies of dominant designs can thus be summarized as follows:

a) firms that adopt the dominant design features will be less likely to exit from the industry;

b) firms that enter the industry during the "window of opportunity" just prior to the emergence of the dominant design, will be less likely to exit; and

c) firms that introduce architectural innovations into new markets will be less likely to exit than will firms that introduce component innovations into existing markets.

All three of these hypotheses are likely to apply to the wireless industry, as follows:

a) firms that adopt the dominant design (in this case, SDR) will be less likely to exit from the industry or lose market share;

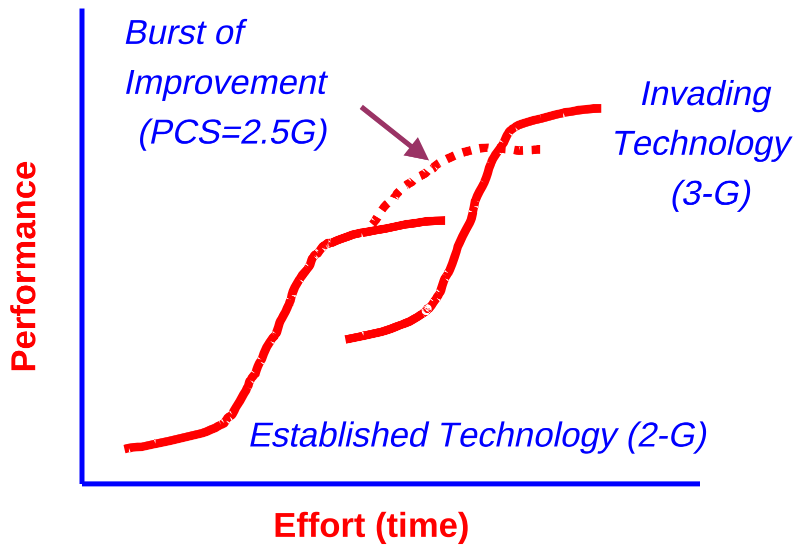
b) firms that enter the industry during the window of opportunity just prior to the emergence of the dominant design will be less likely to exit. The dominant design (SDR) is expected to emerge in the 2000-2001 time frame, with continued maturation and acceptance occurring over the period 2000-2005 and beyond;

c) firms that introduce multi-mode, multi-band, multi-capability innovations into new wireless communications markets will be less likely to exit or lose market share than will firms that introduce traditional component innovations into existing markets.

3.2.2 S-Curves / Disruptive Technologies

The performance offered by a new technology as a function of time is typically described by an S-shaped curve, as shown in Figure 3-4. This concept is important in managing innovation and change and is often used to predict whether an emerging technology is likely to supplant an established one. Technology in this case can be defined as those tools, devices and knowledge that mediate inputs and outputs (process technology), or that create new products or services (product technology)[18]. The S-curve suggests that the magnitude of performance improvement over a product's life cycle varies as the technology matures. In the early stages of a technology, the rate of progress in performance is relatively slow[19]. As the technology becomes better understood and developed, or competition forces more rapid development, the rate of improvement accelerates dramatically; this stage often corresponds to the emergence of a dominant design. The rate of improvement then eventually slows as the technology asymptotically approaches its practical limit. The essence of strategic technology management is to identify the inflection points and take appropriate actions[20]. Failure to respond to such technological changes has forced many firms to exit from markets, and has provided a significant advantage to both market entrants and (existing) attacking firms[21].

Figure 3-4. Technology S-Curves, illustrating burst of improvement in performance of established technology triggered by invading technology.



The dashed line in Figure 3-4 indicates the manner in which established players often fight back with an additional "burst of innovation" in the face of the uprising disruptive technology. However, these last breath efforts eventually run out of steam and the older technology is supplanted. Two examples of such bursts of innovation in the wireless communications industry are:

a) the introduction of narrow-band AMPS prior to the launch of TDMA; and

b) the current launching of many PCS services as an interim step between 2nd- and 3rd-generation wireless communications.

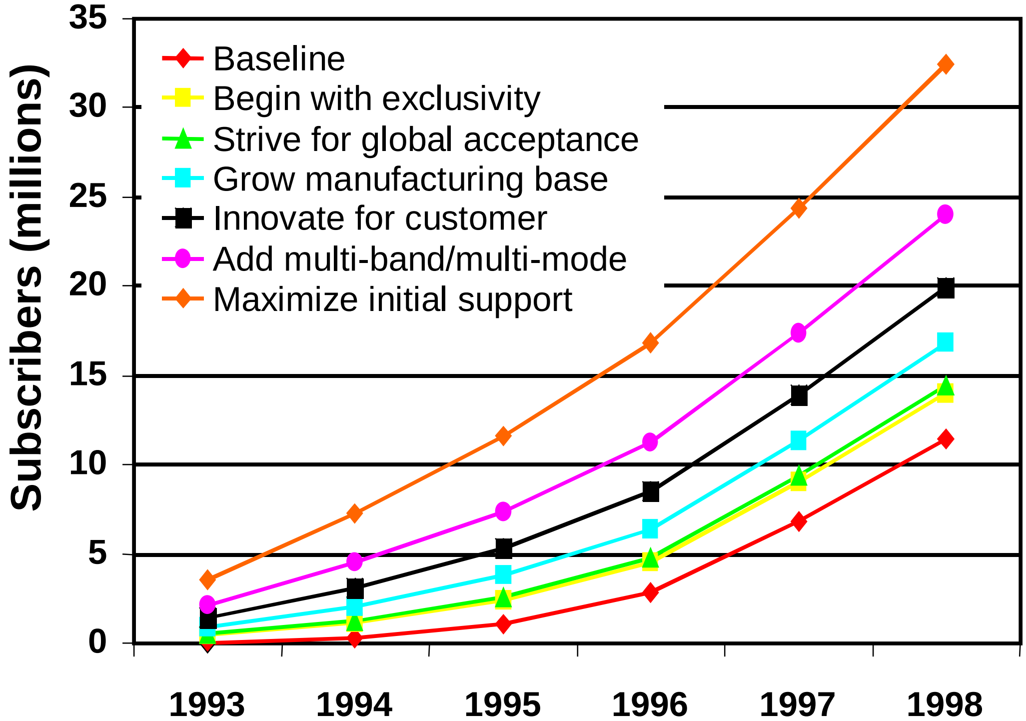
4 - A CASE STUDY OF 3G AND SDR

The five key findings of this study are presented in the following sections. The success strategies for 3G standards identified in section 4.1 are derived from the statistical analysis of technical and market variables described earlier (see Figure 1-3); additional details of the analysis methodology are summarized in Appendix 2. The findings discussed in Sections 4.2 – 4.4 draw on both the in-depth interviews and the industry survey. Section 4.5 focuses on the wireless industry value chain, and draws primarily on the results of the in-depth interviews. Section 4.6 identifies several areas for further investigation.

4.1 Success Strategies for 3G and the Relationship to SDR

A surprising finding emerged from the statistical analysis of success factors of both 1st- and 2nd-generation technologies in the wireless communications industry. In the competition between analog and digital standards, a very small number of market and technology factors has dominated. Figure 4-1 shows the potential magnitude of the influence of each of these factors on the market share gained by competing digital standards. The statistical analysis (see Appendix 2) has been utilized in Figure 4-1 to assess the potential increase in the number of subscribers that could have been achieved by the major competing digital standards over the period 1993-1998. Based on these results, six very clear strategies emerge to steer the successful development of any 3G wireless communications standard. These strategies can be closely related to the advantages offered by the dominant design – SDR.

Figure 4-1. Six factors found to dominate the number of subscribers for competing digital standards.



Strategy #1: Maximize Initial Support

It is absolutely imperative to maximize the number of handset and equipment manufacturing companies who *initially* support the 3G standard. This initial support was found to have been the most significant factor in determining the success of competing digital standards, regardless of later growth in the number of supporting firms. In Figure 4-1, for example, the baseline digital standard could have almost tripled the subscriber base that it had achieved in 1998 by gaining the initial support of additional manufacturers.

The strategic implication of this finding is that one's later competitive position will be vastly improved by organizing as broad as possible a base of industrial and government support for any single new standard than by forging ahead with a minimum number of sponsors.

In practice, such support may be difficult to achieve and another equally valid solution must be sought. SDR can mitigate the impact of multiple standards and provide to end users and others the appearance of uniformity and technology transparency, thereby effectively broadening the base of support.

Strategy #2: Include Multi-band and Multi-mode Capabilities

Multi-band and multi-mode digital capabilities will be critical to the success of 3G standards. In North America, the early availability of dual-mode (800 MHz) TDMA/AMPS and CDMA/AMPS handsets has, if anything, prolonged the reliance of cellular customers on AMPS and slowed the market penetration of digital technologies. Compared to the overall world average as of the end of 1998, the USA and Canada still lag far behind in terms of digital penetration in the cellular marketplace, with 80% of subscribers still using AMPS. The more recent introduction of dual-band 800 MHz/1900 MHz TDMA and CDMA capabilities (which includes AMPS) has done little to offer real value to cellular/PCS customers. In Europe, on the other hand, the introduction of a single digital technology (GSM) and the rapid phasing out of analog services has provided GSM with the opportunity to promote multi-band (900/1800/1900 MHz) handsets as an attractive "world phone" solution to the international roaming problem. Europe, in stark contrast to the U.S., has already "gone digital", with 90% of subscribers using GSM. The Asia-Pacific region, although more heterogeneous than Europe in terms of standards, is already predominantly digital, with PDC and GSM sharing the bulk of the subscriber market. In Figure 4-1, the baseline digital standard could have more than doubled the subscriber base that it had achieved in 1998 by introducing multi-band/multi-mode handsets.

The strategic implication of this finding is that the competitive position of any new standard (and perhaps the coupling of the new standard with an existing standard) will be greatly strengthened by utilizing multi-band/multi-mode capabilities to offer truly new features and services rather than focusing exclusively on backwards compatibility. This latter focus simply prolongs reliance on more entrenched, primitive technologies.

SDR provides a means to support a fluid and dynamic combination of cellular bands and modes according to the needs of a particular geographic region, service provider, or end user. These combinations are often not known in advance, and the traditional approach precludes easy or economically acceptable solutions. Also included in SDR is the ability to develop new features and capabilities to meet the ever more sophisticated demands of business and residential wireless customers.

Strategy #3: Maintain Rapid Technological Innovation; Focus on the Consumer

Following introduction, rapid technological innovation in consumer equipment is a key competitive advantage for wireless standards. The corresponding factor utilized in this study to represent the rate of technological innovation was the rate of increase in handset talk-time/weight ratio. A very clear demonstration of the importance of such innovation is the overwhelming influence that it was found to have on the rapid deployment of PHS systems in Japan. PHS was able to offer subscribers very small, lightweight, and feature-rich handsets, with the result that PHS services became wildly popular in Japan and other Asian countries. It is important to note that technological innovation will be transparent to the end user if it is principally related to the requirements of the network operator, as has been a great deal of digital technology. In Figure 4-1, the baseline digital standard could have almost doubled the subscriber base that it had achieved in 1998 by matching state-of-the-art innovation in cellular handset performance.

The strategic implication of this finding is that the competitive position of any new 3G standard will be greatly strengthened by focusing technological development on offering new features and services that directly impact the end user.

SDR supports the offering of new features and services by providing a dynamic platform that can offer application and service flexibility in conjunction with transparency of the underlying air interface technology.

Strategy #4: Rapidly Increase the Manufacturing Base of Support

It is critical to increase as fast as possible the number of companies who support any new 3G standard. If, for example, CDMA does indeed achieve the forecast dominance over TDMA, it will be due in great part to the successful attraction of a substantially larger base of support. The relative sizes of the respective support camps for today's dominant digital standards can be estimated from the memberships of the CDMA Development Group (CDG) (numbering 96 members[22] as of March, 1998) and the Universal Wireless Communications Consortium (UWCC) (numbering 72 members[23] as of March, 1998 which supports TDMA). On the other hand, the GSM MoU Association, which represents the GSM industry worldwide, numbered 251 members[24] as of March 1998. In Figure 4-1, the baseline digital standard could have increased by 50% the subscriber base that it had achieved in 1998 by increasing more rapidly the number of manufacturers supporting the standard.

The strategic implication of this finding is that the competitive position of any new standard will be greatly strengthened by every effort which is undertaken to expand the number and presence of supporters throughout the industry.

SDR allows new entrants and incumbent suppliers to add one or more 3G standards to any air interface standards that they may already support. SDR provides a path for vendors to reduce the number of unique air interface combinations that they must support via different product models. By offering a flexible evolutionary path from 2G to 3G, SDR also broadens the user base and hasten overall acceptance of 3G standards.

Strategy #5: Strive for Global Acceptance

It is important to have any new 3G standard adopted in as many major international regions as possible. Regional standards, such as PDC and PHS, and perhaps even still TDMA and CDMA to some degree, stand to be eventually displaced in the wireless communications market by standards offering global portability. The continuing success of GSM, which is the only standard with a significant presence in all major markets worldwide, attests to this fact. In Figure 4-1, the baseline digital standard could have increased by at least 25% the subscriber base that it had achieved in 1998 by gaining commercial acceptance in additional regions throughout the world.

The strategic implication of this finding is that the competitive position of any new 3G standard will ultimately depend on the ability with which sponsoring organizations are able to influence international standards debates, and international partnerings and alliances, and adoption by network operators throughout the world.

SDR is a solution that can act as a unifying force across disparate technologies. It can remove decision uncertainty about deployment of a particular technology; as SDR becomes a pervasive core technology, the selection of any particular standard becomes less of an issue.

Strategy #6: Begin with Exclusive Adoption in a Major Region

Although international adoption is the ultimate goal, this study has clearly identified the competitive advantage to be gained for any new 3G standard by achieving exclusive adoption of the standard in a major international market region. The initial success of AMPS in North America, and later of GSM in Europe, as well as PDC and PHS in Japan, all attest to this fact. In Figure 4-1, the baseline digital standard could have increased by at least 25% the subscriber base that it had achieved in 1998 by initially gaining exclusive adoption in one major region.

The strategic implication of this finding is that the early sponsoring organizations of any new standard must also strive to influence local standards debates, and to set up suitable local partnerings and alliances, so as to initially carve out an exclusive position at least in the their own home region. This local stronghold may very well prove to be of great strategic importance in the transition toward 3G wireless standards.

However, the capabilities and advantages of SDR as a dominant design may obviate the need for any local adoption stronghold to be established.

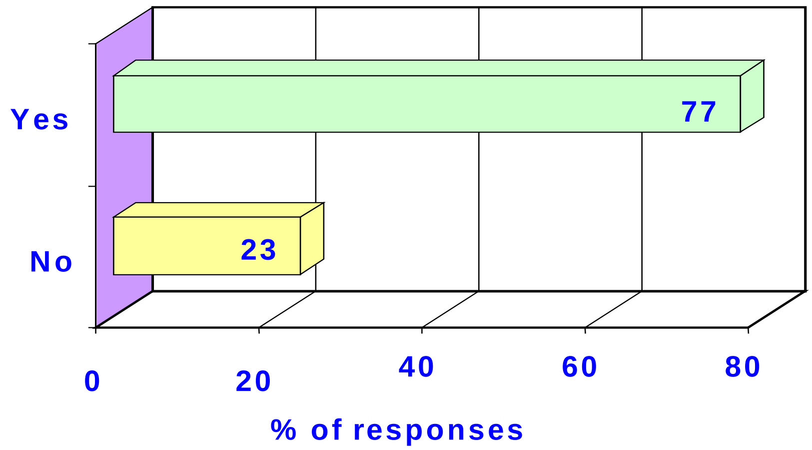
4.2 Software Phones Offer the Most Promising Solution to Multiple Standards

In the MIT Survey there was a strong consensus among industry experts that a single standard is unlikely to emerge from the current IMT-2000 process. On the other hand, it was felt that the number of globally accepted digital standards will likely be reduced to three, or perhaps two. Recent developments have revealed the emergence of three strong camps, each promoting the development of an IMT-2000-compliant but backwards compatible variant of one of the three major existing digital standards (TDMA, GSM, and CDMA):

- UWC-136 or Universal Wireless Communications, the IS-136 TDMA follow-on.
- UTRA W-CDMA or UMTS Terrestrial Radio Access: Wideband CDMA, the GSM follow-on.
- cdma2000 or Wideband CDMA, the IS-95 CDMA follow-on.

As shown in Figure 4-2, the majority of respondents answered "yes" to the question:

"Do you think SDR is a viable solution to the multi-standard environment? Why or why not?" **Figure 4-2.**



Respondents' comments supporting the viability of SDR included:

- SDR has already been implemented for several years in base stations, and the flexibility offered by over-the-air reconfiguration has proven both its feasibility and its commercial value. The network flexibility offered by the combination of SDR in both handsets and base-stations is now widely recognized and sufficiently attractive from the operators' standpoint that it will be pursued to the point of commercialization.
- Several research efforts have already demonstrated the feasibility of multi-mode/multi-band SDR handsets, and several new ventures (both start-ups and new ventures internal to larger corporations) are moving these results into the development stage.
- Faced with severe heterogeneous network problems, service providers and network operators are beginning to mobilize the resources necessary to create the sufficient "market pull" for SDR.
- Chip manufacturers have been pursuing related development efforts with sufficient resources to have solved all key problems related to mixed signal formats, processing speed, and power consumption. The groundwork has been laid for the next stage of commercial development.
- The influence of PC/PDA technologies has moved wireless communications into the consumer electronics realm, and SDR is simply a far too appealing and logical "next step" for it not to happen. Critical mass has also been reached in the development of streamlined operating systems for hand-held consumer electronic appliances that could support SDR functionality.
- SDR has now gained sufficient visibility throughout all key wireless industry segments, and it is now deemed to be a viable solution by a sufficient critical mass of industry players.
- Development of the necessary security and encryption technologies have been accelerated by the Internet industry, and are sufficiently advanced to enable viable SDR products and services.
- Over-the-air service downloads are already available in a number of wireless communications products, and they have proven to be both attractive to customers and lucrative to sellers.
- 3G wireless technologies will provide suitable bandwidth and network support to enable basic SDR functionality. Rapid, widespread acceptance is expected to follow.

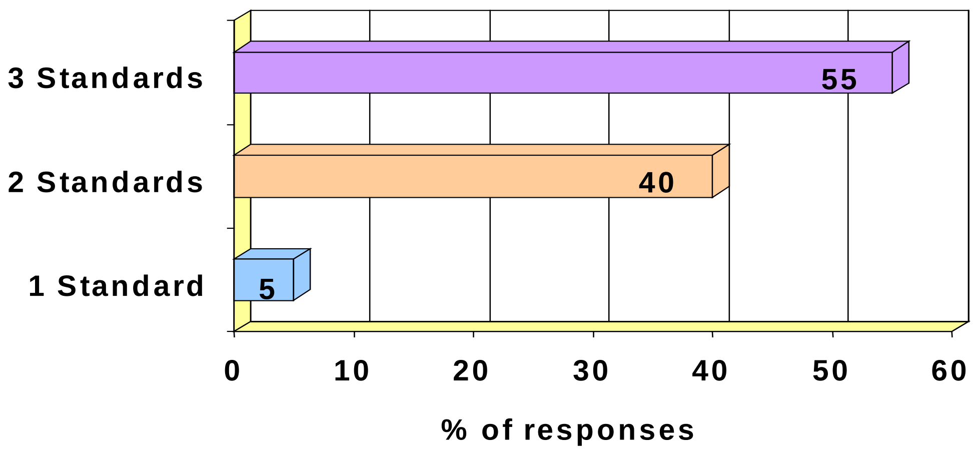
Concerns raised by respondents included:

- So-called “Velcro phone” solutions are cheaper. Silicon solutions will win out both in terms of price and time to market.
- SDR cannot become commercially viable without an industry-standard operating system. Such an OS will not be developed and agreed upon in time for SDR to be incorporated into 3rd-Generation standards deliberations.
- SDR may very well be technically feasible, but it would be far too expensive to install. Installed networks would have to be replaced or upgraded, neither of which are affordable in the foreseeable future.
- Given the financial outlays already underway to upgrade from analog networks to digital and PCS networks, service providers are simply too financially strapped to go ahead with SDR.

Industry experts overwhelmingly indicated that the 3G standards process would substantially reduce the number of worldwide wireless standards. The results are shown in Figure 4-3.

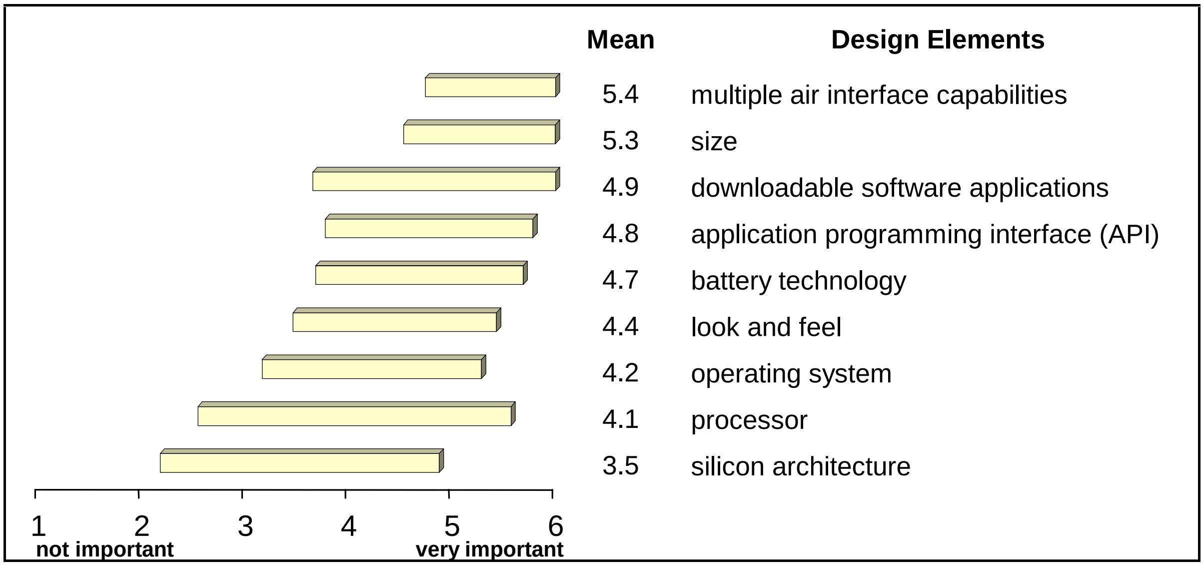
What do you think will happen in the wireless industry with regards to the proliferation of new technologies and competing air interfaces?

Figure 4-3.



Wireless industry participants ranked multiple air interface capabilities as the most important design elements in terms of determining the commercial evolution of *software phone* technologies and products, as shown in Figure 4-4.

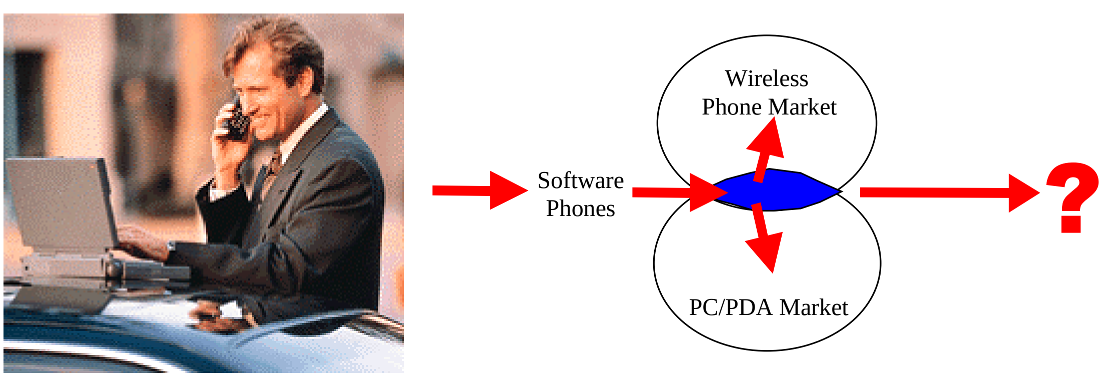
Figure 4-4. Ranking in importance of software phone design elements. The range of responses is also indicated.



4.3 Software Phones Have Gained Momentum by Helping to Unite Two Major Markets

As the lines between the technology developments and market forces of the cellular phone and Personal Digital Assistant/Handheld PC (PDA/PC) industries blur, (see Figure 4-5), a market opportunity is created, for both incumbent firms and new entrants. The complementary capabilities of the technologies of these two market segments are inherently embodied in the software defined radio appliance, which may be viewed as a potentially disruptive innovation that is creating some market turbulence.

Figure 4-5. Two major industries united by the software phone.

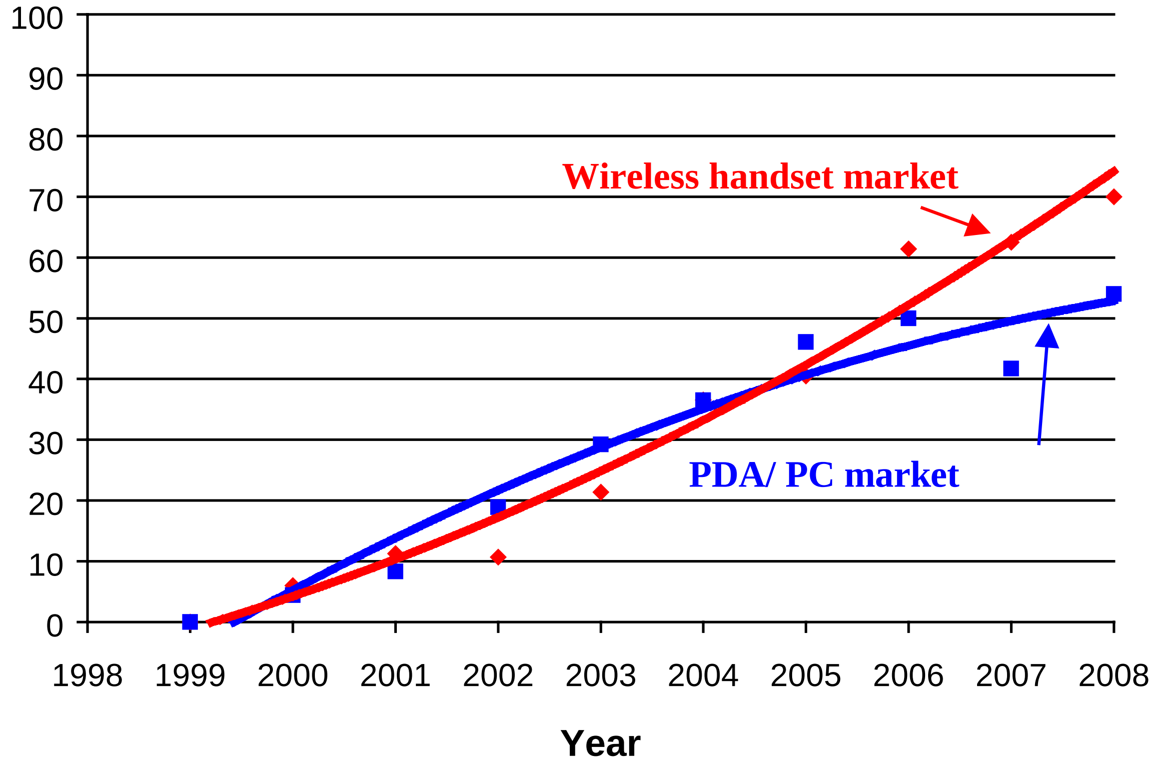


The software phone is perceived to be an extremely powerful technology that will enable wireless service providers to offer their subscribers many attractive new value-added services. Software phones are also perceived to be an extremely lucrative opportunity for traditional manufacturers of hand-held PCs and PDAs to expand into the wireless communications market. These two perceptions may prove to be critical in accelerating the development of software phones, given that the first signs of weakening PC demand and flattening cellular service revenues are appearing.

SDR itself is not widely perceived to be a wireless appliance or network *standard*, but rather a potential *design element* to be incorporated into a future standard or standards.

The growth of the software phone will be dependent on how quickly it can penetrate into both wireless phone and PDA/PC markets. Figure 4-6 presents the expectations of industry participants for the future penetration of software phones into the wireless handset and PDA/ PC markets.

Figure 4-6. Expected penetration of the software phone into wireless and PDA/PC markets.



The results indicate that the industry experts interviewed expect software phone appliances to penetrate the wireless phone market more quickly than the PDA/PC market, with a 75% market penetration expected into the former by the year 2006. In the PDA/PC market, software phone appliances were predicted to reach 60% market penetration by the year 2006.

4.4 Software Phone Concepts are Being Rapidly and Widely Accepted

Industry experts responded positively to the question:

What aspects of the SDR concept do you think are gaining acceptance?

Comments from the industry experts included the following:

- SDR has already proven itself to be commercially viable and technically beneficial in base-stations. The necessary hardware technologies are all out of the research stage and into development.
- The flexibility offered by digital software implementations of signal processing algorithms is becoming more widely acknowledged.
- Cost/size reductions for handsets offering advanced multi-media features would be substantial using SDR.
- SDR would enable an enormous reduction in handset inventories.
- The ease and utility of over-the-air SDR upgrades is a very attractive feature of a growing number of business plans.
- Wireless bandwidth-on-demand is a consumer demand that only SDR can fulfill.
- SDR has been proven feasible in handsets for both multi-mode and multi-band applications.
- Advanced, downloadable applications and pay-as-you-use services offer service providers a very attractive potential revenue stream.
- There is now a great deal of SDR-related activity in the wireless industry, both at technical and business-development levels. There now exists a clear sense among leading edge carriers that SDR can and will happen.
- An ever-growing number of independent applications vendors are becoming well versed in audio, video, and wireless technologies. Much as has happened with the Palm Pilot in a very short period of time, these independent vendors will be in a position to quickly jump on board any emerging SDR bandwagon, so that the consumer impact will expand rapidly.
- SDR allows network capacity to be optimized on the fly by reconfiguring both base-stations and handsets.
- SDR would enable PC-like communications appliances, single pieces of hardware that have a broad range of possible functional configurations. The resulting economies of scale greatly favor SDR over alternatives.

4.5 Support for SDR Varies Across the Value Chain

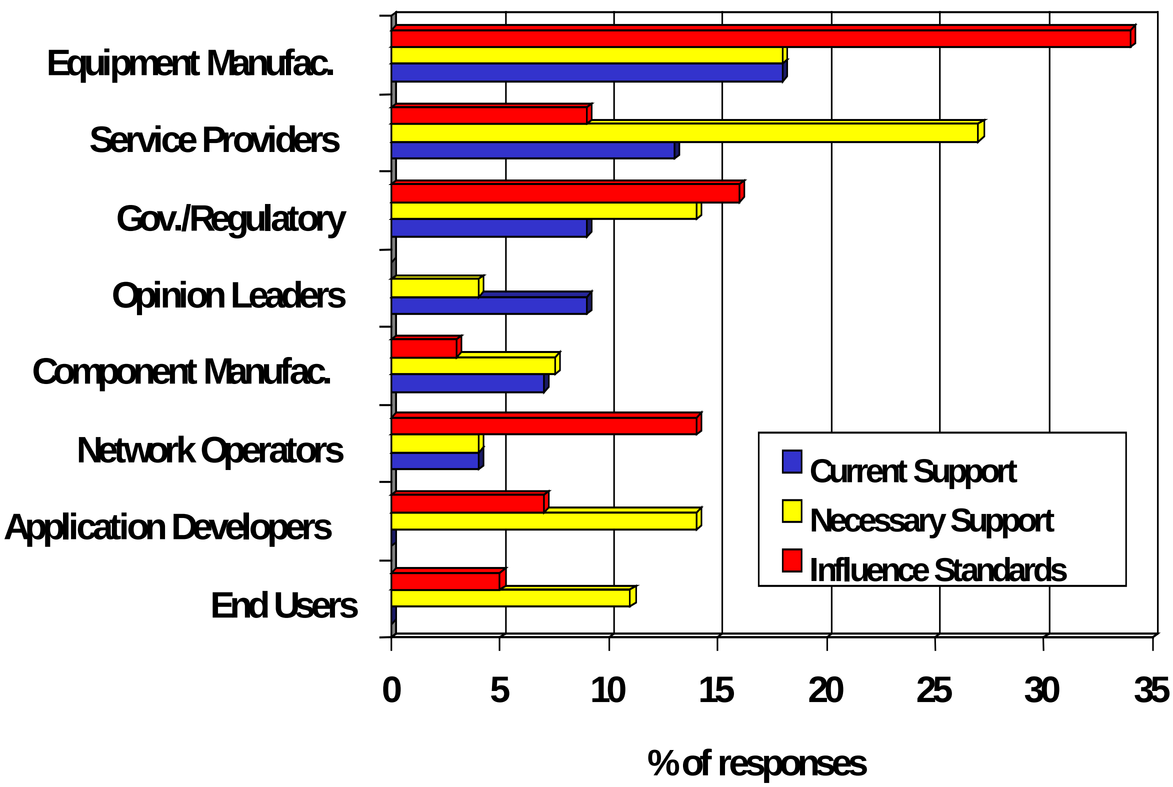
Industry experts were asked several questions related to current and future support for SDR within the wireless industry. These questions were framed in terms of the wireless industry value chain. The results are presented in Figure 4-7.

Who is actively supporting SDR today in the global wireless industry?

Who would have to actively support SDR in order for the technology to achieve global acceptance?

Who do you think will have the most influence on the further evolution of international wireless standards?

Figure 4-7.



The value chain links showing the greatest disparities between current support and necessary support are the service providers, application developers, and end users. Equipment manufacturers and government/regulatory agencies are expected to have the greatest influence on future standards development.

4.6 Areas for Further Investigation

Industry experts also highlighted several issues that must be resolved when asked:

What aspects of the SDR concept do you think may be problematic in terms of gaining global acceptance?

- There are many potential degrees of SDR implementation, ranging from a simple call by call switching between different air interfaces to complete wide-band digital processing of the entire available spectrum. Some interviewees felt that, until service providers agree on a common level of SDR deployment, introducing SDR handsets today would only further exacerbate the technology proliferation problem. Others felt that an opportunity existed for more technologically aggressive and consumer-oriented service providers to begin deploying SDR-based services that offer competitive advantages to those high-end customer segments who typically are first to adopt new information technologies (such as the financial services industry).

- Pursuing SDR would require many companies to undertake difficult structural alterations to avoid, for example, internal struggles between network infrastructure and SDR handset development efforts.

- Extensive roaming agreements would have to be set up, and service providers have proven to be very inflexible in the past.

- It would be necessary to incorporate key aspects of SDR into 3G standards proposals, and this is unlikely to happen soon enough.

- Many groups have been established within the wireless industry to advance various technology and standards agendas (GSM MoU, UWCC, CDG, MDI, UMTS, etc.). The successful “selling” of SDR would require winning the support of many of these groups, but they are unlikely to be willing to work together on a problem of this scope.

- Many hardware issues remain to be resolved, including: suitable high-speed broadband analog-to-digital converters, sufficiently fast and low power DSPs or general-purpose processor chips.

- SDR technology is not yet mature enough to pursue a combination GSM/CDMA handset, which would be a key element of any commercial SDR service.

- Tri-mode GSM phones will soon offer the sort of global roaming that SDR was meant to provide.

- A convincing need for SDR handsets has not yet been demonstrated, and cost constraints are far too tight.

- There is not sufficient focus. Those who are currently pursuing SDR seem to be stretching the SDR paradigm to encompass everything that is currently wrong with wireless.

- Traditional wireless equipment providers will find it very difficult to learn to think and act like consumer electronics firms, and SDR is a consumer electronics product.

- A very broad range of skills will be required for SDR development teams. Cementing the necessary alliances between a large number of new and established hardware and software developers will be necessary, but very challenging.

- A great deal of international standards development would be required. But the world is highly polarized today, with Europe being exceedingly “standards-friendly” while the U.S. continues to insist that only free markets can pick the “right standard”.

- North American carriers are still shelling out funds to complete analog to digital and digital to PCS upgrades. They are neither willing nor able to pursue the next revolution in wireless technologies.

- SDR proponents still have not clearly defined exactly what it is that they will offer to end users and how much it will cost.

- It will be many years before sufficient bandwidth is available to offer practical real-time downloading of the sort of applications that SDR must provide.

- Hand-off when switching between different air-interfaces will be very difficult to implement. Equipment suppliers and network operators traditionally do not work well together on such problems.

5 - CONCLUSIONS

As wireless communications technologies migrate ever further into the consumer electronics arena, the demands imposed by mass markets are revolutionizing accepted design principles. Under the pressure to develop low-cost consumer wireless communications products, two sharply divergent approaches have emerged. The more traditional hardware development route is to compress digital radio technology onto an ever smaller number of silicon chips in order to achieve semiconductor industry economies of scale. The opposing effort seeks to transform radio from its present hardware-dominated status into a technology dominated by digital software – the software phone. Most industry specialists whom we have interviewed during our study concede that the collision of the cellular telephony and personal computer industries favors the eventual emergence of software phone as the dominant design for a broad variety of "hybrid" handheld products. However, the severe constraints on size, power consumption, and cost imposed by consumer handheld appliance markets will require continuing advances in both hardware and software technologies in order to realize the full potential of the software phone. This four-part study has been carried out to assess the potential for software phones to emerge as the dominant design for future generations of wireless communications systems. The four components of the study have resulted in the following conclusions.

Lessons from Other Industries

Studies of the influence of dominant design emergence in other rapidly changing industries have led to three hypotheses that are likely to apply to the wireless industry, as follows:

- Firms that introduce multi-mode, multi-band, multi-capability innovations into new wireless communications markets will be less likely to exit or lose market share than will firms that introduce traditional component innovations into existing markets.
- Firms that adopt the dominant design for multi-mode, multi-band, multi-capability (in this case, SDR) will be less likely to exit from the industry or lose market share.
- Firms that enter the market during the window of opportunity just prior to the emergence of the dominant design will be less likely to exit. The dominant design is expected to emerge in the 2000-2001 time frame, with continued maturation and acceptance occurring over the period 2000-2005 and beyond.

One can also conclude from our analyses that software phones may have a much greater impact on the wireless industry if they can be promoted as a dominant design element that enables the creative synthesis of existing wireless technologies and standards, rather than as a radical leap to a new trajectory.

In-Depth Interviews with Wireless Industry Experts

Interviews with wireless industry leaders revealed the following assessments of the level of awareness of software phone technologies and the likely receptivity of the wireless industry to such an innovative new technology.

- Software phone concepts are widely recognized throughout the wireless industry. The software phone itself is not widely perceived to be a wireless appliance or network standard, but rather a potential design element to be incorporated into such standards. Software phones are expected to emerge as niche products at the convergence of the wireless phone and PDA/PC markets.

- Due to its emergence from the collision of the cellular phone and PDA/PC industries, the software phone is regarded as a potentially disruptive innovation. This collision has already created both significant market turbulence and many opportunities for both market incumbents and new entrants.

- The software phone is perceived to be an extremely powerful technology for wireless service providers to offer their subscribers many attractive new value-added services. The software phone is also perceived to be an extremely lucrative opportunity for traditional manufacturers of hand-held PCs and PDAs to expand into the wireless communications market.

- The software phone can enable two distinct functions: reconfigurable air interfaces and reconfigurable applications. Many reconfigurable applications could be built into hand-held cellular appliances with wireless modems today, using existing cell-phone and hand-held PC standards. Reconfigurable air interfaces, on the other hand, will require further developments in both hardware and software technologies.

- There are many potential degrees of software phone implementation, ranging from a simple call-by-call switching between different air interfaces to complete wideband digital processing of the entire available spectrum. Until service providers agree on a common level of software phone deployment, introducing software phones today would only further exacerbate the technology proliferation problem.

- There is a strong consensus that a single standard is unlikely to emerge from the current IMT-2000 process. On the other hand, it was felt that the number of globally accepted digital standards will likely be reduced to two or at most three, and that software phones enable roaming in such an environment.

- Recent developments have revealed the emergence of three strong camps, each promoting the development of an IMT-2000-compliant but backwards compatible variant of one of the three major existing digital standards (TDMA ,GSM, and CDMA):

  - UWC-136 or Universal Wireless Communications, the IS-136 TDMA follow-on.

  - UTRA W-CDMA or UMTS Terrestrial Radio Access: Wideband CDMA, the GSM follow-on.

- cdma2000 or Wideband CDMA, the IS-95 CDMA follow-on.

- Inclusion of basic software phone elements in IMT-2000 standards, even in a more limited role, will be a key element to convince semiconductor manufacturers to accelerate the development necessary to allow large-scale commercial introduction of the software phone within 5 years.

- There is a growing number of industry and government groups involved in various aspects of wireless standards deliberations. This proliferation of interest groups should be addressed by the SDR Forum in order to accelerate the development of software phones.

- A window of opportunity exists for high-data-rate cellular services while cable companies continue to delay their introduction of broadband services, while traditional telecomm firms struggle to improve the economics of fiber-to-the customer and other high-speed digital services, and while new satellite services are being built out. The end user will gain influence as these alternative broadband service options become available. On-time service turn-on and real service quality will play a major role in determining who wins the battle for the customer.

- Cost-benefit tradeoffs must be much more efficiently communicated across the wireless value chain in order to promote the use of the software phone. Communication between potential producers and users of software phone technologies appears to be insufficient to enable the formulation of product and service definition, pricing estimates, and market segmentations.

- Service providers were identified as the most influential group in the wireless industry value chain in terms of their potential impact on the software phone. In particular, software phone R&D and advanced development efforts within these organizations should be bolstered in order to reach a critical mass of support.

Statistical Analysis of Technical and Market Variables

In this component of the study, the evolution of 1^{st}- and 2^{nd}-generation wireless communications technologies and standards was examined in detail in order to seek common trends that are likely to repeat themselves during the invasion of 3G wireless technologies. Six key market and technological factors were identified as having a significant influence on the relative success of competing 1^{st}- and 2^{nd}-generation wireless standards. These factors are expected to play a similar role in the competition between 3G standards.

- It is absolutely imperative to maximize the number of handset and equipment manufacturing companies who *initially* support the standard. Although not found to be significant for competition among analog standards at the outset of the cellular industry, this initial support is clearly shown to have been perhaps the most significant factor in determining the success of competing digital standards, regardless of later growth in the number of supporting firms.

- Multi-band and multi-mode capabilities will be critical to the success of 3G standards. The competitive position of any new standard will be greatly strengthened by utilizing multi-band/multi-mode capabilities to offer truly new features and services rather than focussing exclusively on backwards compatibility. This latter focus simply prolongs reliance on more entrenched, primitive technologies.

- Following introduction, rapid technological innovation in consumer equipment is a key competitive advantage for wireless standards, but the focus of this technological development must be on offering new features and services that directly impact the end user.

- It is critical to increase as fast as possible the number of companies who support any new standard. The competitive position of any new standard will be greatly strengthened by every effort that is undertaken to expand the number and presence of supporters throughout the industry.

- It is important to have any new standard adopted in as many major international regions as possible. The competitive position of any new standard will ultimately depend on the ability of sponsoring organizations to influence the outcome of international standards debates, the foundation of international partnerings and alliances, and the degree of adoption by network operators and service providers throughout the world.

- Although international adoption is the ultimate goal, this study has clearly identified the competitive advantage to be gained for any new standard by achieving exclusive adoption of the standard in a major international market region. The early sponsoring organizations of any new standard must also strive to influence local standards debates, and to set up suitable local partnerings and alliances, so as to initially carve out an exclusive position at least in the their own home region.

Survey of Industry Participants

Feedback gathered from wireless industry participants revealed the following expectations for future software phone products:

- The software phone is expected to take on a new hybrid form, resembling elements of the cell phone and personal digital assistant form factors. Handset size and multiple air interface capabilities will be the most dominant design elements in terms of determining the commercial evolution of software phone technologies and products.

- While software phone development will be influenced by both the wireless phone and PDA technological blocks in terms of hardware and software, more influence is expected to come from the wireless phone.

- The general consensus of the commercial availability of the software phone is at the end of the third quarter in the year 2000. For the software phone to emerge in the year 2000 there is a strong indication that further developments in both hardware and software are required.

- The standard market segmentation of business and consumer is the leading favorite for software phones. Of importance to the business market is compatibility with other wireless products, size, and battery life. The consumer market, on the other hand, favors cost, look and feel, and compatibility with other PDA/PC products.

- The software phone is expected to penetrate both the wireless phone market and PDA market; penetration into the wireless phone market is expected to proceed more rapidly than into the PDA market. In the wireless phone market, the software phone is expected to attain an estimated 75% market penetration by the year 2006. In the PDA market, the software phone is expected to achieve 60% market penetration by the year 2006.

APPENDIX 1 - GLOSSARY

Air interface Set of techniques for transferring information between base stations and mobile terminals.

Burst of innovation Deviation from the typical S-curve, highlighting the manner in which established players often fight back by enhancing the performance of existing products in the face of an uprising disruptive technology.

Collateral assets A firm in possession of collateral assets - or *co-specialized* assets – such as market channels, brand image, and customer switching costs, will have some advantage over its competitors in terms of enforcing its product as the dominant design.

Dominant design The design, within a product class, that wins the allegiance of the marketplace. The dominant design may take the form of a new product or a well-designed set of product features.

FPLMTS Future public land mobile telecommunications system, the original concept for 3G wireless systems developed by the International Telecommunications Union (ITU).

Innovation, competence destroying Typically introduced by new firms, and leading to increased market turbulence.

Innovation, competence enhancing Typically introduced by existing firms and leading to decreased market turbulence.

Multi-band cellular phone A cellular phone capable of operating at several different frequency ranges.

Multi-mode cellular phone A cellular phone capable of operating over several different air interfaces.

Network externalities The value to a customer of a product increases as the number of compatible users increases.

S-curves S-shaped curves used to describe the typical performance offered by a new technology as a function of time.

Risk, market Entering an emerging market with a proven component technology.

Risk, technological Entering an established market with new, higher performance component technology.

SDR Software defined radio, or software radio: set of techniques to implement most radio functions as software algorithms, thus allowing mobile terminals and base stations to download a software implementation of a fully-functional, multi-band, multi-mode wireless communications appliance.

Software phone personal communications appliance embodying the functional properties of a thin-client network computer, a personal digital assistant, and a cellular phone.

APPENDIX 2 – STATISTICAL ANALYSIS

The primary source of data for this part of the study was EMC, the world's number one independent single-industry-focused supplier of market intelligence for the cellular/PCS industry. Located in Surrey, England, EMC provides continuously updated information and data, gathered from a global network of researchers. EMC's specialist researchers collect the data by regular visits to network operators, handset and infrastructure equipment manufacturers, and service providers. They also attend conferences and seminars in over 70 countries each year. As a result, EMC is now acknowledged in the wireless industry for collecting, recording, and collating one of the largest and most complete range of cellular market data using largely primary sources. The database covers the historic period from 1983 to present, and also includes five-year forward looking projections (currently out to 2002).

The EMC databases are maintained on a Lotus Notes server. Each database can be searched via several different "views", which present selected data-fields in spreadsheet form. The data can then be exported to commonly-used spreadsheet programs or statistical analysis packages for further processing, analysis, or plotting. Most of the database components can be searched by analog/digital technology, by country, or by major region. The technologies and regions covered by the EMC databases are listed in Table A2-1.

Table A2-1. Cellular technologies and world regions for which data has been compiled in the EMC databases.

Analog Technologies	***Digital Technologies***	***World Regions***
AMPS	GSM	Africa
TACS	TDMA	Asia-Pacific
NMT-450	CDMA	Americas
NMT-900	PDC	Middle East
C-450	PHS	Europe
NTT		USA/Canada
RC-2000		

The M.I.T. team was given access to the complete set of EMC databases. Data-mining activities focused on information covering three general categories:

- *Subscriber statistics:* The EMC database tracks cellular/PCS subscribers by analog and digital standard, by region and by country.

- *Subscriber equipment:* The EMC database tracks cellular/PCS handsets by analog and digital standard, by manufacturer, and by date of market introduction. Additional information has also been collated on handset size, weight, talk time, standby time, etc.

- *Network Equipment:* The EMC database tracks cellular/PCS network installations by analog and digital standard, by region and country, by equipment manufacturer, by network operator, and by date of network launch.

All subsequent sorting and plotting of the data was carried out using the Microsoft Excel spreadsheet program. All statistical analysis was carried out using SPSS 8.0 for Windows.

Data was mined for >40 variables variables, and assembled by cellular standard and major region (see Table A2-1). Unless otherwise noted, data was assembled on a quarterly basis, covering the period Q1-1983 to Q1-1998 for analog standards and Q1-1992 to Q1-1998 for digital standards. For all variables corresponding to numbers of subscribers, five-year forecasts were also gathered for 1998-2002. Table A2-2 below lists those variables that emerged as being statistically significant following regression analyses. All significant pair-wise correlations were eliminated from the models.

Table A2-2. Names and descriptions of variables found to be significant in regression analyses.

Variables	*Description*	*Rational*	*Significance*
SUBSCRIBE (dependent)	Number of subscribers worldwide for each standard.	Fundamental dependent variable	Both Analog and Digital standards
EXCLUSIVE	Number of major regions in which each standard is the single analog or digital standard in use.	Indicative of ability of standard to achieve regional dominance.	Digital standards only.
REGION	Number of major regions in which each standard is in use.	Indicative of ability of each standard to achieve global dominance.	Both Analog and Digital standards.
MANUFAC	Total number of companies introducing new handset models or completing infrastructure equipment installations.	Indicative of manufacturing support achieved by each standard.	Both Analog and Digital standards.
INITIAL	Number of companies initially supporting each standard.	Indicative of manufacturing support already in place for each standard at time of launch.	Digital standards only.
INNOVATE	Rate of change of average talk-to-weight ration of handsets for each standard (minutes/gram per quarter).	Indicative of the influence of the pace of technological development for each standard.	Both Analog and Digital standards.
MM/MB	Availability of Multi-band or Multi-mode handsets incorporating each standard.	Indicative of the influence of the availability of multi-mode and multi-band technologies.	Both Analog and Digital standards.

Details of all variables for which data was assembled and for which regression analyses were carried out are presented elsewhere[25]. Separate analyses were carried out for analog and digital standards. Models were tested based on a variety of dependent variables, including absolute numbers of subscribers, quarterly changes in numbers of subscribers, market shares, and quarterly changes in market shares. Each regression model combined the relevant sets of data for all (analog or digital) standards, in order to assess the overall dependence of the selected group of predictor variables. The most statistically significant models were built utilizing absolute subscriber numbers as the dependent variable.

Results of the regression analyses are presented in Table A2-3 for the worldwide growth of analog cellular subscribers and Table A2-4 for the worldwide growth of digital cellular subscribers.

Table A2-3. Summary of regression model for variables influencing worldwide growth of analog cellular subscribers. Dependent variable: SUBSCRIBE (number of subscribers worldwide for each analog standard, in millions). R=0.95.

Variable	*Short Description*	*Coefficient*	*Standard Error*	*Significance*
MM/MB	Multi-band or Multi-mode handsets	23.79	0.98	0.001 level
REGION	Number of regions using standard	1.22	0.20	0.001 level
INNOVATE	Rate of technological innovation	108.30	25.88	0.001 level
MANUFAC	Number of manufacturers for standard	0.60	0.16	0.001 level

Table A2-4. Summary of regression model for variables influencing worldwide growth of digital cellular subscribers. Dependent variable: SUBSCRIBE (number of subscribers worldwide for each digital standard, in millions). R = 0.89.

Variable	*Description*	*Coefficient*	*Standard Error*	*Significance*
INNOVATE	Rate of technological innovation	170.00	27.43	.001 level
INITIAL	Number of initial manufacturers	2.13	0.40	.001 level
MM/MB	Multi-band or Multi-mode handsets	6.29	1.91	.01 level
REGION	Number of regions using standard	1.46	0.71	.05 level
MANUFAC	Number of manufacturers for standard	0.54	0.26	.05 level
EXCLUSIVE	Single standard in a major region	2.58	1.44	.1 level

Residual analysis[26] was also carried out in order to verify the validity of the regression analyses. For each regression model, *standardized residuals* were plotted both as a function of the predicted values of the dependent variable and as a function of time.

The results presented in Figure 4-1 utilize the regression coefficients given in Table A2-4, and assume the following changes in the six independent variables with respect to the baseline case:

INITIAL +10 (i.e. increase by 10 the number of handset or infrastructure equipment manufacturers who supported the standard at time of launch).

MM/MB +2 (i.e. add multi-band and multi-mode capabilities to handsets)

INNOVATE +.05 minute/gr per fiscal quarter (i.e. roughly doubling the average rate of technological innovation)

MANUFAC +10 (i.e. add the support of 10 more handset or infrastructure equipment manufacturers over the period studied, 1993-1998)

REGION +2 (i.e. add 2 major regions using the standard)

EXCLUSIVE +1 (i.e. add one major region in which the standard is used exclusively)

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