Mobile Computing in Next Generation Wireless Networks

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ABSTRACT

In this paper, we attempt to describe the evolving status of wireless communications and its impact on the future of mobile computing. We present a historical perspective and elucidate the technical challenges facing mobile computing in the next generation of wireless networks. Next generation wireless includes the cellular evolution towards third generation systems (W-CDMA, cdma2000, etc.) and the proliferation of high-speed wireless indoor office networks. From global roaming to innovative applications, the next generation of wireless communications promises to enable a level of mobile data connectivity and capability that is unprecedented. However, many challenges concerning network and terminal designs remain.

Keywords

Wireless data, IMT-2000, cdma2000, mobile computing

1. INTRODUCTION

Wireless networking has experienced remarkable growth during the last few years and has every indication of reaching even higher levels of subscription [1]. With the coming of the next generation, air interface standards will exist that will allow even more users to access cellular systems. In conjunction with consumer growth, corporate use of wireless local area networks is growing in popularity and creating growing demand for mobile office solutions. It is predicted that by the turn of the century, the market for wireless data networks will grow to 6 to 8 million users accounting for roughly 7 percent of the global wireless revenues. Wireless data traffic is expected to account for over 70 percent of the total by 2003.

Mobile computing in the next generation will allow for applications such as high-speed access to the corporate Intranet, and to the public Internet via the World Wide Web (WWW). The web is generally seen as the most prominent application driving consumer markets and is the most widely recognized and used application in the consumer base. With the arrival of Digital Subscriber Lines (DSL) and cable modem technologies [2], high speed Internet to the home is becoming a reality and is expected to generate a huge market.

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While more information is being placed on internal corporate web sites, high-speed web access will also be a fundamental tool for the mobile professional. Web access grows at an alarming rate, driving data traffic to roughly double every two years. Market penetration of Internet users stands at 40% in the US and is growing. Perhaps one of the only things to keep pace with the alarming growth of the Internet is the growth of the mobile communications market. Specifically, wireless data subscriptions are expected to increase thirteen-fold by the year 2003 to 36 million customers [3]. It is only natural that these two burgeoning facets of communications will begin to come together.

Fueling this convergence of high speed web browsing with mobile access are the evolution of cellular systems that will bring order of magnitude increases in transmission speeds, the development of end terminal devices with human interfaces capable of displaying complex graphical presentations, and increased dependence and preference for networked information. High speed mobile computing enables applications like electronic newspapers, stock trading, and e-commerce that take on added value when users are mobile or working away from their offices or homes.

The next generation of wireless networking promises to offer dramatic improvements in terms of bit rates, advanced Medium Access Control (MAC) layers, power saving techniques, and data transmission capabilities. These developments will lay the groundwork for significant advances in mobile computing in the next decade and beyond.

2. Current Wireless Networks

Wireless networks have their origins in dispatch services. In the late 1930's the Chicago police department experimented with one of the earliest mobile networks to provide short messages and dispatches to their patrol cars. Cellular networks, as we recognize them today, first appeared in the early 1980s. These first generation networks employed analog modulation techniques and were standardized as Analog Mobile Phone Systems (AMPS). End terminals for AMPS were large hulking devices that required heavy batteries, often relegating them to remain as fixtures connected to the automobile power system. AMPS operated under a Frequency Division Multiple Access (FDMA) scheme where a logical channel is achieved by assigning portions of the frequency spectrum to users for dedicated sole use. This is the same principle that governs radio and television stations that broadcast their information in a pre-assigned frequency band.

Wide area cellular networks are a reality today because of the cellular concept of frequency reuse. Cellular providers are allocated a small portion of radio spectrum in which they can divide into separate frequency channels to transmit and receive signals. Signals of the same frequency create interference to one another and in order to properly distinguish signals, frequency use must be planned very carefully across geographic regions. Thus emerged the concept of a cell. A cell is a geographic region served by one base station antenna system that uses a subset of the service providers allocated frequencies. Surrounding cells then operate with different and distinct subsets of frequencies so as to not interfere with the interior cell. In this manner a degree of geographic separation is achieved between cells operating with the same subset of frequencies. This helps to mitigate interference problems caused by two same frequency channels (co-channel interference) and allows service providers to effectively reuse portions of their spectrum in different geographic areas. The level of susceptibility to interference in the modulation technique and the radio propagation effects of the system including radiated power, terrain and atmospheric effects determine the degree of reuse.

AMPS signals and receivers are very susceptible to co-channel interference, therefore AMPS systems require a large geographic separation of frequencies. This negatively impacts the service provider's capacity per unit area and does not provide very efficient use of the spectrum. Another drawback of AMPS is the open modulation scheme that is not encrypted and provides no measures against eavesdropping and jamming. Cellular fraud resulting from malevolent use of intercpted cellular signals represents a huge problem for service providers, estimated at close to 1 billion dollars by the Cellular Telecommunications Industry Association (CTIA) for 1996 alone. Low capacity, insecure communications, and no provisioning for non-voice applications characterize the first generation cellular landscape. In the early 1990's service providers began to deploy what is now termed second generation cellular. The second generation of cellular systems was heralded by the arrival of digital modulation techniques that promised increased capacity, better speech quality, enhanced security features, and more efficient terminals. Current cellular networks are of the second-generation variety. Multiple access schemes that found strong acceptance in the second-generation cellular networks were Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). TDMA channels both frequency and time in the sense that transmissions are slotted in time and a user is uniquely identified by the carrier frequency and time slot of their transmission. CDMA on the other hand distinguishes users on the basis of unique, very rapidly changing binary codes. All users in a CDMA system transmit at the same time and on the same frequency carrier but can be uniquely identified by decoding their transmissions with the appropriate binary code. CDMA is analogized to a large loud international cocktail party where many conversations are occurring simultaneously, however native speakers of English can extract the English from the mix of other languages. As CDMA exhibits a resiliency to the mutual interference caused by simultaneous transmission, it can theoretically circumvent the need for reuse planning. This allows for simpler cell site planning, more efficient use of spectrum and enhanced capacity for service providers.

There are two existing implementations of cellular systems based on TDMA technologies, and one based on CDMA. The two TDMA systems include Interim Standard-136 (IS-136) in North America and Global System for Mobile (GSM), which is a pan-European standard supported widely throughout Europe and the rest of the world. The CDMA system is referred to as Interim Standard 95 (IS-95), developed by Qualcomm Inc. and has a large presence in North America, Latin America, Korea, and elsewhere.

GSM and TDMA differ in the amount of bandwidth used for a frequency channel and the number of time slots that exist on one channel. TDMA divides access to a 30 KHz bandwidth into 6 time slots, while GSM incorporates 8 time slots into a bandwidth of 200 KHz. IS-95, meanwhile, uses its distinct codes to modulate a signal over a frequency channel that is 1.25 MHz wide.

Digital coding and modulation of voice can fit more users into a given channel than AMPS and can be manipulated to provide encrypted transmission. These digital formats facilitated the development of data operations over wireless systems and marked a starting point for mobile computing in cellular networks.

While second generation systems improved the capacity, security, and quality of AMPS, they were however not suited for full-blown high speed networking access. Systems, protocols, and devices were designed primarily for voice applications. Bit rates were mired in the 9.6 Kbps range and terminals were designed to resemble cordless phones, with very limited memory, processing power, and graphics capability. Recent advances in second-generation systems will increase the bit rate slightly and provide greater capacity through improvements such as smart antennas, interference cancellation, and multi-user detection. Despite these advances however, current cellular networks are not well suited for the demands of enhanced mobile computing.

3. Current Status of Mobile Computing

While cellular networks have enjoyed a steady evolution to the present, so has the nature and capability of mobile computing. As devices become smaller and more portable, the demand for computing and networking solutions while on the move has increased steadily. From the earliest laptops and electronic address books to the current offering of slim notebook computers and PalmPilots, the device and terminal market has been driving towards smaller, more powerful devices. This has whetted the appetite of the mobile professional. Whereas before one would have to suffer through short battery lives and tiny simplistic displays, now the mobile user can enjoy larger screens and increased battery times. Mobile computing is being facilitated by the proliferation of a myriad of hand-held devices that span the application spectrum from address books and calendars to palm-sized computers integrated with telephony capability [4]. More mobile devices are entering the market place with specific functionality and are capable of synchronizing with the fixed network and keeping the mobile professional up to date. These devices represent the first wave of terminals aimed at the mobile computing user and still have many hurdles to overcome in order to fully exploit the full range of services and applications.

Presently, wide-area wireless data services are implemented using first (AMPS) or second (IS-136 and GSM) generation cellular telephone networks. In the US, CDPD (Cellular Digital Packet Data) service is implemented as an AMPS overlay network. CDPD offers a raw data rate of 19.2 Kbps shared by all data users within a cell. CDPD is accessed via a wireless modem. IP protocol is adopted to access the Internet. GSM and IS-136 networks offer circuit switched data access at a rate of 9.6 Kbps per channel. Generalized Packet Radio Service (GPRS) is expected to be deployed under GSM with an initial data rate of 100 Kbps. EDGE (Enhanced Data Rates for GSM Evolution) promises data rates of 300 Kbps

The advances of wireless networking in the office are equally as promising. With current IEEE 802.11 technology corporate employees can enjoy untethered access to the company Intranet, the public Internet, and remote files at speeds approaching 2 Mbps [5]. Also as wireless LAN equipment continues to drop in price and complexity, home wireless networking is beginning to take shape and create markets.

3.1 Problems with Present Mobile Computing

The success of mobile computing today is hampered by many debilitating factors. These include slow networks, wasteful protocols, disconnections, weak terminals, immature IP access to networks, poorly optimized Operating Systems (OS) [6] for mobile applications, content conversions from wired to wireless networks, among others.

One of the most critical factors holding back mobile computing in the cellular arena is that the available bandwidth for second-generation networks does not facilitate the type of high-speed access that most people have come to enjoy from their desktop. Mobile computing applications are still treated as a special evolving arena where slower speeds and limited services are tolerated for the convenience of being mobile. Wide-area mobile computing, in a form similar to its fixed desktop cousin, can not be realized on a large scale comparable to cellular telephony until access speeds increase.

Cellular networks have been optimized for voice since their inception. This has impeded the development of cellular data growth. The protocol development for cellular systems has not been congruent with protocol development for wired networks. This serves as a blocking point for seamless data networking over wired and wireless networks.

Another major impediment to the success of mobile computing in second generation networks is the lack of terminals that can handle expressive graphics and long text messages. Today's second generation phones allow only a few lines of text and have Graphical User Interfaces (GUI) that are not intuitive and natural to use from a computing standpoint. This makes it very difficult to perform even simple tasks such as retrieving email. Issues such as how to handle attachments and incorporate hyperlinks into the text that is displayed on the handset have yet to be solved or standardized.

4. IMT-2000 and the Great Leap Forwards

While second generation cellular systems are in place today across the world, the third generation (3G) is fast approaching. This effort is being driven by the International Telecommunications Union (ITU) International Mobile Telecommunications 2000 (IMT-2000) project. The ITU is a United Nations organization charged with overseeing issues affecting global communications. The IMT-2000 project is a plan to specify and standardize a global communications structure that would allow for high-speed seamless mobile access. The use of the 2000 in the project title is two-fold and dually misleading. It is meant to imply a new wave of wireless and mobile communication systems that will operate in the 2000 MHz frequency band across the globe and be operational by the year 2000. However, global frequency planning does not have a frequency band in the 2000 MHz range that is cleared for use throughout the world, and expected deployment of IMT-2000 is now expected to occur well after the millennium. The ITU solicited proposals for potential IMT-2000 Radio Transmission Technologies (RTT) and received over 10 terrestrial and 6 satellite transmission proposals.

The ITU released specifications for each IMT-2000 proposal that included minimum bit rates for various levels of user mobility including 2 Mbps for indoor low mobility, 384 Kbps for pedestrian situations, and 144 Kbps for high speed vehicular environments. In addition to the order of magnitude increases in bit rates, IMT-2000 systems will offer advanced IP networking capability, global interoperability, enhanced QoS mechanisms, and adaptive software downloadable IMT-2000 terminals. This will provide a platform for enhanced quality and versatility of mobile computing access. Figure 1 shows the relative position of IMT 2000 in the global spectrum of standards. It is clear that IMT 2000 offers superior coverage at multiple terminal speeds and has the ability to operate both indoors as well as outdoors.

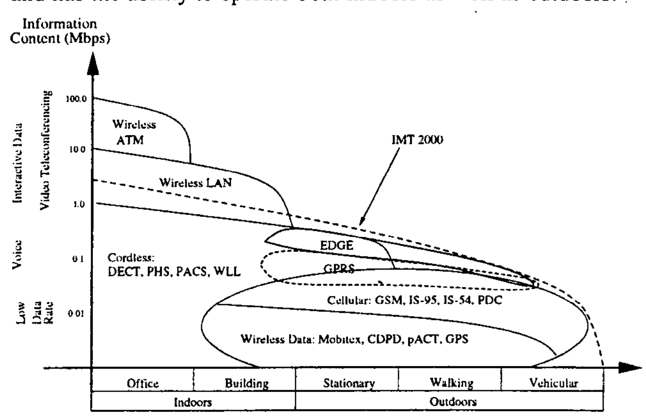

Figure 3: Spectrum of wireless technologies

Through a harmonization process the 10 proposals were reduced to 3 distinct terrestrial air interface specifications including two next generation extensions to CDMA and an evolved TDMA proposal. The CDMA proposal developed by Qualcomm, called cdma2000 [7], extends the current second generation IS-95 system and most easily migrates the current second-generation CDMA equipment in North America. The standards body in North America, the Telecommunications Industry Association (TIA), supports this proposal. The other CDMA proposal, Wideband-CDMA (W-CDMA) [8] is a pan-European specification developed by the GSM proponents in Europe and by companies in Japan. W-CDMA is designed as a greenfield system that does not use existing radio interface infrastructure or integrate with existing second generation channel planning. This technology is supported by the European Telecommunications Standards Institute (ETSI) in Europe [9] and by the Association of Radio Industries and Businesses (ARIB) in Japan [10]. The extensions proposed for TDMA for the third generation include using higher modulation (8PSK as opposed to QPSK) and migration to the GSM 200 KHz carrier and framing structure coupled with a high speed packet protocol known as Generalized Packet Radio Service (GPRS). The physical layer of this proposed evolution is referred to as Enhanced Data Rates for GSM Evolution (EDGE) [11].

The IMT-2000 is based on a "family of systems" concept where IMT-2000 would serve as an umbrella set of requirements that individual radio technologies would have to implement. The European effort towards IMT-2000 is called Universal Mobile Telecommunications Systems (UMTS) and will be a member of the IMT-2000 family. UMTS will then interoperate with other 3G technologies that are also member technologies of the IMT-2000 family.

As separate standards and regulatory bodies govern development for particular regions, implementation of IMT-2000 systems will progress at different rates across the globe. Japan is expected to be the first region to commercially deploy an IMT-2000 compliant system. The Japanese service providers are perhaps the most motivated to standardize and launch an IMT-2000 system as the Japanese government has conditioned the release of any additional spectrum to be only for IMT-2000 compliant use. It has been projected that Japanese deployment will begin in the year 2001. IMT-2000 will see a delayed introduction in the United States as implementation will be market driven and service provider's migration strategies are yet unclear. It is anticipated, however, that deployment may come by 2003. European deployment is still unclear but is expected to occur on pace with North America or shortly before.

4.1 IMT-2000 Services and Capabilities

In IMT-2000 compliant systems, mobile users will be able to access the Internet, make voice calls, receive streaming media such as audio and video, and transfer large data files while on the go and away from their home networks. This will be facilitated by the interoperability of disparate network domains, secure tunneling of information across foreign networks, and through IP enabled mobility schemes such as Mobile IP (MIP) [12].

The order of magnitude speed increases brought by IMT-2000 will greatly increase the service portfolio for mobile computing in cellular networks. It will also increase the demand for high bandwidth services in what can be viewed as a "virtuous circle". As more high speed mobile services and applications are deployed and accepted in the business and consumer marketplace, there will be an increased need to have even more high bandwidth mobile services. We can see this phenomenon in the public Internet. Having large stores of information and an easy, intuitive interface make the web an attractive means to access that information. The web then becomes a more common and preferred means of information retrieval, prompting even more information to be put on the web. Mobile computing services could be subject to the same principal of increasing self generating utility as mobile subscription and mobile accessibility to data and services grows. Potential applications for high bandwidth mobile connections include medical imaging for doctors in the field, real time road maps for vehicles, remote video broadcasting, and a host of other services.

To help support these enhanced services, IMT-2000 systems will possess more advanced Medium Access Control (MAC) layers that are capable of handling concurrent independent traffic. For instance the cdma2000 Radio Transmission Technology (RTT) document describes an advanced MAC layer that will be able to support concurrent streams at different QoS levels and frame error rate targets. The MAC layer performs admission control, scheduling, and prioritization of packet bursts between the terminal and the base station [13]. One can then imagine applications where users can expect dynamic support for simultaneous voice, video and data. As the MAC layer can establish variable and independent QoS targets for each traffic stream, the voice and accompanying video can be intelligently traded off in situations where there is not enough bandwidth available to support both at high quality simultaneously.

A goal for third generation mobile systems is to provide universal coverage and to enable terminals to be capable of seamless roaming between networks, which may be of differing types. The current thinking is that the services will negotiate with the radio bearer via an adaptation layer to secure channels in each direction, having the required characteristics of bandwidth, delay and quality, also recognizing that many multimedia communications will be highly asymmetric.

Examples of this concept include a videoconference that begins in the office at 2 Mbps. As a participant walks out to the parking lot the bit rate is degraded to 384 Kbps. At this point the video could be scaled back from high-resolution color to simple black and white. As the user continues onto the bus and commutes to another office location at high speeds, the video could be cut out all together in light of the lower bit rate. Then as the user arrives at the other office site, the high-quality videoconference could be brought back as she enters the building and the bit rates increase.

IMT-2000 recognizes that there is a growing need to accommodate a maximum level of interworking between networks of different types to provide customers with greater coverage and consistency of services. This includes cellular, PCS, paging and data networks and services. What is needed in support of this interworking is a system that provides much greater flexibility. Such flexibility would enable operators to configure and manage their networks in accordance with the service demands of the market. Ideal flexibility includes the following characteristics: multi-functionality, multi-environment capabilities, multi-mode operation, and multi-band flexibility. This will be facilitated by the use of multi-mode terminals, software defined radios, and enhanced interoperability functions. IMT-2000 is then concerned with evaluating the feasibility of more flexible techniques for the radio interface. Flexible control is needed not only to adapt a mobile terminal to a number of different interfaces and environments, but also to enable real-time control and dynamic tuning of basic parameters (modulation, channel coding, etc.) to optimize performance and spectrum efficiency.

This mobile computing evolution is due in large part to network design that accommodates wireless data transmission protocols. Second generation cellular did not have IP access on the phone, and did not address the needs of high-speed error sensitive data transmission like large file transfers. The third generation is bringing a more networking conscious paradigm that incorporates more advanced computing applications than simple voice. Where once only low bit rate applications like Short Message Service (SMS) were practical for mobile terminals, now enhanced real-time multimedia and database access are possible.

Advances in the network and protocol side of next generation wireless systems are also increasing the range and applicability of mobile computing. Mobility management techniques such as MIP will allow terminals to maintain IP connectivity while in different administrative domains. And secure tunneling will allow mobile professionals to securely access corporate Intranets while in remote locations using non-corporate networks.

With the coming of third generation cellular systems also comes the beginning of location based services. The FCC has mandated that cellular systems be able to physically locate the position of mobile terminals within 125 meters over 66% of the time [14]. With this new capability many rich, value added services will become available and will have impact on many different industries. The most critical being emergency medical and public safety services. Other applications range from travel to advertising. For instance mobile users could land in a foreign country and have their pocket terminals locate the nearest restaurants, hotels, and information centers. In a more active vein, one can imagine more aggressive advertising that can target mobile subscribers when they are within proximity of a business. In such a situation, a restaurant could form an arrangement with a cellular service provider with a base station nearby that whenever a mobile user is within a close enough proximity to the restaurant, a message could be sent notifying them of the daily special. These types of services allow the mobile terminal to be made aware of its context and empower the mobile subscriber with advanced communication and information opportunities.

5. Challenges for Mobile Computing

While the future of mobile computing in the context of next generation cellular networks looks promising, there are many challenges still to overcome to make it a reality.

Some of the challenges facing researchers today involve the myriad optimization problems that are present within mobile computing in a 3G cellular environment. Issues such as optimal radio resource use in a crowded medium, efficient power saving algorithms that attempt to optimize throughput for dynamic environments subject to mutual interference, and most efficient use of limited spectrum are but a few of the current research topics. As mobile computing will put a greater emphasis on data communications and as voice begins to play less of a dominant role in the third generation, resource management techniques that apply to data traffic, instead of voice type traffic, need to be investigated. One example of this type of ongoing research can be found in [15]. This work addresses the issue of power control in wireless data networks as opposed to voice networks and takes a game theoretic approach to the problem of assigning transmitter powers to users of error sensitive data applications. Here the cell is modeled as an economic system and the users are driven to maximize their utility. As data applications require the correct receipt of all bits, as opposed to voice, which can drop frames without a perceived loss in quality, utility is equated to the number of bits that can be successfully transmitted in the lifetime of the terminal battery.

We will also see that the complexity presented by an increased user base with access to high-speed services will present problems in the areas of terminal mobility and disconnection management. While there are myriad optimization problems that require research, there are also many challenges that face hardware developers, software developers, content providers, service providers, and network managers alike.

5.1 Terminal Design Challenges

One of the most pressing challenges facing the future of widespread mobile computing is the availability of appropriate end devices. Today most users of cellular networks access the system through a small hand-held device whose functionality and form are very closely tied to voice telephony. Most devices have limited display capability; perhaps a few lines suitable for displaying phone numbers and small icons. These displays most often lack the graphics power and resolution to display images, fonts, colors, and animation. Also the human interface for inputting data into the cell phone is usually limited to a few menu buttons at a numeric keypad. Clearly these devices do not provide an ideal interface to the visually complex and rich environment of the World Wide Web.

Current laptop computers are another option for the mobile data user. These devices are much larger, heavier, and bulkier than cellular telephones, but they provide extremely enhanced graphics, memory, and processing capabilities, many times rivaling or exceeding, traditional desktop computers. Their displays are much larger with increased resolution, and the interface for inputting data is intuitive and familiar.

Thus a compromise must be reached that trades processing power with portability. We can see this tradeoff realized in the current offerings of Personal Digital Assistants (PDA), which forego telephony altogether, such as the PalmPilot from 3COM and Palm-sized computers such as the Cassiopeia form Casio. These devices are designed for more visually orientated activities and include larger displays and intuitive menu systems. Also these terminals provide more memory and computational power than the traditional cellular telephone. Qualcomm has realized a crossbreed named pdQ Smartphone that integrates the calendar and personal organizer functionality with a digital cellular phone. The widespread acceptance and popularity of the latest PalmPilot, the Palm VII organizer which allows for wireless access to email and specific web sites, is an indicator that terminal design is evolving with the mobile customer in mind. This trend must continue and more intuitive interfaces need to be developed for interactive wireless computing to meet and exceed its high expectations.

Another drawback to conventional electronic devices as a means for mobile computing is the limited battery power and short lifetime before recharging. Most cell phones can handle live voice conversations for around 6-10 hours before their batteries need to be recharged. The power requirements to support video, complex digital signal processing, and computationally intensive applications are much higher than those for simple voice conversations. We can see this in the limited battery lifetimes of current laptop computers that are on the order of 4-8 hours. Advanced MAC layer protocols that attempt to conserve power for high-speed transmission, such as [16] and [17], need to be researched and implemented to improve the quality of mobile computing. These types of power saving algorithms will be a critical component of the mobile networks and represent a challenge to mobile computing researchers.

5.2 Evolution of the Internet to Enable Mobile Terminals

In conjunction with the challenges facing appropriate terminal design for mobile computing is the challenge of presenting information content to limited display terminals [4]. A number of initiatives attempt to address the problem of formatting web sites and other electronic information for transfer onto current mobile devices. As advances in terminal displays are being made, they are a still a long way from the quality of the desktop displays that web content was originally designed to be viewed on. Therefore efforts need to be made to adapt the complex visual data of the Internet for the more limited capabilities of mobile computing devices. For instance the Wireless Access Protocol (WAP) is attempting to be the de-facto world-wide standard for providing Internet communications to digital mobile phones, pages, personal digital assistants and other wireless terminals. The WAP protocol is furthered by large industry participation in the WAP Forum, which is a collection of handset manufactures, content providers, and software developers. The objective of the WAP Forum is to bring Internet content and advanced data services to mobile terminals by developing a global wireless protocol specification that will work across differing wireless network technologies [18].

The operating systems used for mobile computing also represents challenging areas for evolution. Operating systems for wireless information devices differ from their desktop counterparts in three fundamental ways. One, they must be lightweight and not require extensive resources from the CPU. Secondly, they must be power conscious and not be wasteful of the terminal's battery life. Thirdly they must be designed to handle frequent outages, unstable communication channels and synchronization effects. There are many companies actively involved in developing operating systems specifically for wireless information devices including Symbian, Microsoft, 3COM, and Sun Microsystems among others. The operating system behind the PalmPilot device is the PalmOS developed by 3com. This operating system has been implemented in many Smartphone products released by Qualcomm, Nokia, and Ericcson. Microsoft is aggressively marketing its WindowsCE operating systems for use in mobile phones, communicators, and PDAs as well. Recently it was announced that 3COM would incorporate Sun's Java technology into its Palm computing platform. This would allow Java's runtime environment for consumer products to be tightly integrated with the PalmOS. These types of partnerships signal a convergence of wired networking technologies with wireless and will be significant in furthering the capability and utility of mobile computing.

Other efforts towards making Internet information more palatable to display impoverished terminals include web sites that act as portals specifically for mobile devices. One such example is Lucent's Zingo that will provide specific information for mobile professionals which will allow content published in standard HTML format to be automatically reformatted for virtually any device with a built-in browser [19]. Microsoft Corporation has also taken a similar step with the introduction of its own web portal, MSN Mobile, aimed at providing information and services to mobile customers.

These types of initiatives point to a marked convergence of wired and wireless networking that needs to occur to further the state of mobile computing. Wired networks need to become more conscious of the wireless end devices that access them in order to provide tailored information and services suitable to the device's capability and context.

5.3 High Speed Data and Mobility

As transmission speeds increase by an order of magnitude, and packet data services become more prominent in the cellular arena, there is a growing concern surrounding the issues of mobility. The topic of resource management for multimedia traffic as mobiles cross over cell boundaries will be of increased importance in the third generation. Provisions for disconnection and reconnection management in this new framework need to be addressed. Network functions such as caching and re-synchronization are placed in a new light as access speeds, the intensity of handoffs, and the heterogeneity of networks increases. There is also a need to understand the demands of dynamic flexible service configurations for high-speed multimedia mobile communications [20]. This will be particularly important as the bit rates and network resources will vary across different physical environments.

5.4 Migration to the Third Generation

Second generation systems and infrastructure are widely deployed and supported. In addition, a huge base of existing customers already exists and will continue to exist into the 21st century. Potential IMT-2000 operators do not want to have to discard all their existing infrastructure, rather they would prefer that the new system should coexist and interwork with the present one and act as an adjunct to it. An orderly evolution path from second generation to third generation is required. Any migration towards the third generation must be approached with care to preserve the significant investments that service providers have in their legacy equipment. As of yet there are no clear migration strategies for service providers to adhere. Thus the timing of IMT-2000 implementation and commercialization is unclear. This may disrupt the availability of mobile computing services and applications. Therefore, this migration strategy plays a key role in the offering and subscription of mobile computing.

5.5 Quality of Service

Another goal of the third generation systems is to offer some means by which quality of service may be guaranteed. This is a particularly difficult issue in the context of wireless communications as the channel is time varying, and subject to interference, and fading. There have been proposals for extensions of RSVP to the mobile environment [21] but the performance of such schemes, and the ease of implementation have yet to be determined.

Offering differentiated service quality also raises interesting questions in terms of billing and accounting. If a service provider is going to charge customers for a "premium" service, such as higher bit rates or lower delay, then there must be mechanism by which the service provider can quantify the actual performance that user receives. This introduces a good deal of complexity to integrate into the overall network management and accounting systems of the network.

6. Conclusion

With the impending implementation of IMT-2000 systems, the next generation of cellular systems shows promises in advancing the status mobile computing significantly. These new communication systems will usher in a new mobility enabled communications paradigm that will allow new modes of computing applications and services. Access speeds approaching

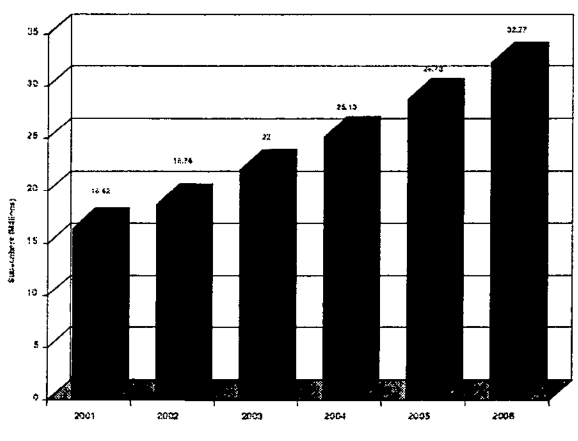

Figure 2. Third Generation Wireless Market Potential in the U.S.

2 Mbps, terminals that allow intuitive access to services, seamless and global operation across heterogeneous networks, and protocol design to facilitate packet data will further the wide spread acceptance of mobile computing as a preferred means to access networked information. The number of mobile professionals is increasing, as is the amount of information being placed on secure corporate web sites and the public Internet. Wide area cellular systems that provide high-speed web access coupled with advances in terminal and interface design, could be the driving factor that makes mobile computing as ubiquitous and natural as fixed and cellular telephony is today. These developments offer the promise of extending enhanced data services to a vast number of subscribers. Evidence of this can be seen Figures 2 and 3. Figure 2 shows that the number of U.S. subscribers to 3G services is predicted to steadily grow to around 32 million by the year 2006. Figure 3 illustrates that the worldwide growth of mobile subscribers will outpace that of the fixed network and total subscription levels of mobile customers will exceed that of the fixed network by the year 2010.

The groundwork is being laid now for this promising future through the evolutions towards IMT-2000 of current second-generation cellular systems (IS-95B, GPRS, etc.) and through the proliferation of handheld organizers and smartphones. Both the access systems and the access terminals must grow and mature in congruence, if the full potential of the mobile computing revolution is to be realized.

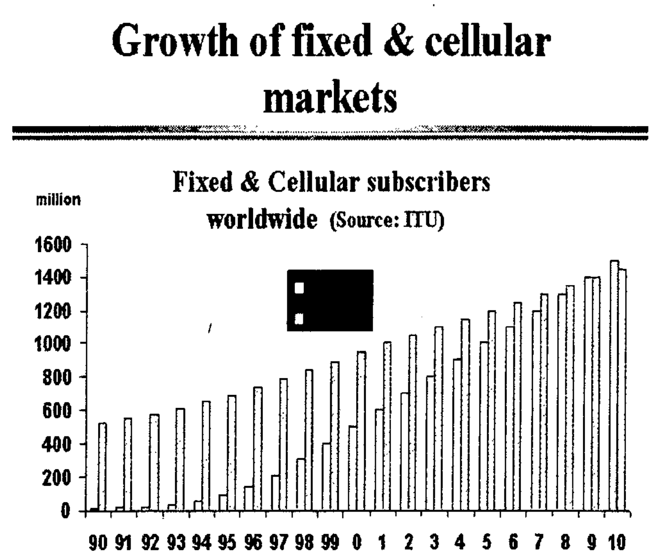

Figure 3. Number of Fixed and Cellular Subscribers Worldwide

This may be a daunting task as regulatory bodies are slow to standardize IMT-2000 systems and as service providers hash out their migration strategies. The time frame for this mobile computing revolution is unclear and there exist many technical and research challenges. However, it is certain that the next generation cellular systems will provide fertile ground for new applications, never before imagined, to spring up and provide innovative *anytime, anyplace* and *anymedia* service to customers roaming the globe. With the help of a number of corporate collaborations among wireless and data communications equipment manufacturers, service providers and software developers, subscribers to voice, data and multimedia communication services will reap the benefits of the synergies brought into play by combining the best of many technologies.

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