Challenges for Mobile Wireless Devices for Next Generation in Pervasive Computing

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***Abstract* — Network computing and mobile computing are fast becoming a part of everyday life. We expect devices like PDAs, mobile phones, offices PCs and even home entertainment systems to access information and work together in one integrated system and the challenge is to combine these technologies into a seamless whole and on the Internet. The aim of Pervasive Computing is for computing available wherever it's needed. It spreads intelligence and connectivity to more or less everything. So conceptually, ships, aircrafts, cars, bridges, tunnels, machines, refrigerators, door handles, lighting fixtures, shoes, hats, packaging clothing, tools, appliances, homes and even things like our coffee mugs and even the human body and will embedded with chips to connect to an infinite network of other devices and to create an environment where the connectivity of devices is embedded in such a way that it is unobtrusive and always available. Pervasive computing, therefore, refers to the emerging trend toward numerous, easily accessible computing devices connected to an increasingly ubiquitous network infrastructure.**

What is really different about mobile wireless device? The devices are smaller and bits travel by wireless rather than Ethernet. How can this possibly make any difference? Isn't a mobile system merely a special case of a distributed system? Are there any new and deep issues to be investigated, or is pervasive computing just the latest fad? This paper is my attempt to answer these questions.

***Index Terms* — AMPS, CDMA, GSM, IMT-2000, Pervasive Computing, Ubiquitous Networks.**

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I. INTRODUCTION

Wireless networking has experienced remarkable growth during the last few years and has every indication of reaching even higher levels of subscription. With the coming of the next generation, air interface standards will exist that will allow even more users to access cellular systems.

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, high speed Internet to the home is becoming a reality and is expected to generate a huge market.

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.

II. Current Wireless Networks

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 preassigned frequency band.

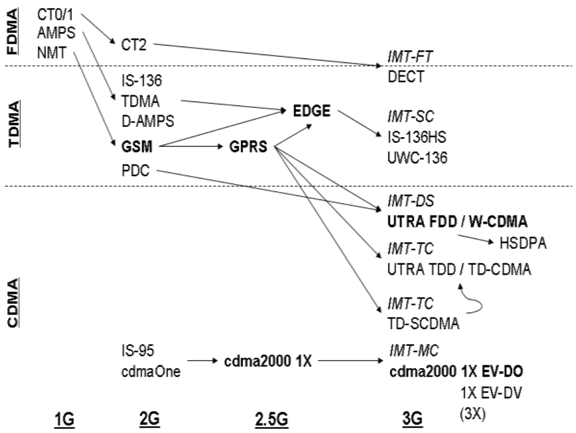

Fig. 1: Development of Mobile Telecommunication Systems

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 the concept of a cell emerged. A cell is a geographic region served by one base station antenna system that uses a subset of the service provider 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.

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. Low capacity, insecure communications, and no provisioning for non-voice applications characterize the first generation cellular landscape.

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.

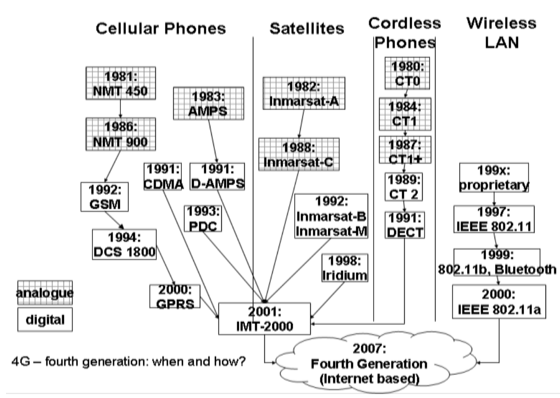

Fig. 2: Wireless Systems: Overview of the Development

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.

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.

III. Current Status 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 Palm Pilots, 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.

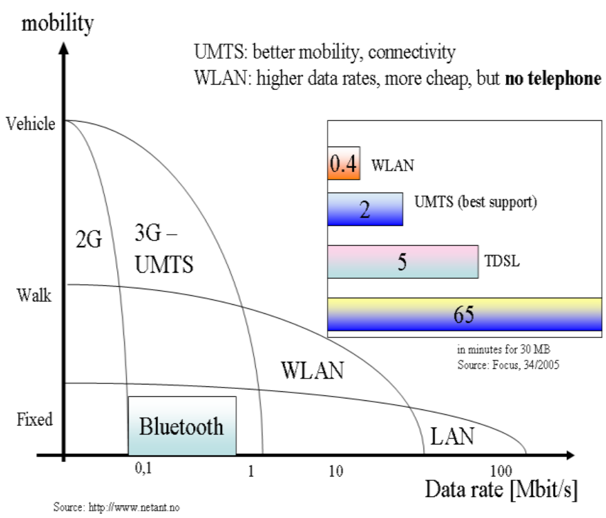

Fig. 3: Mobility and Data Rates

Presently, wide-area wireless data services are implemented using first (AMPS) or second (IS-136 and GSM) generation cellular telephone networks. 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. With current IEEE 802.11 technology corporate employees can enjoy uninterrupted access to the company Intranet, the public Internet, and remote files at speeds approaching 2 Mbps.

IV. IMT-2000 & 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 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 below 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.

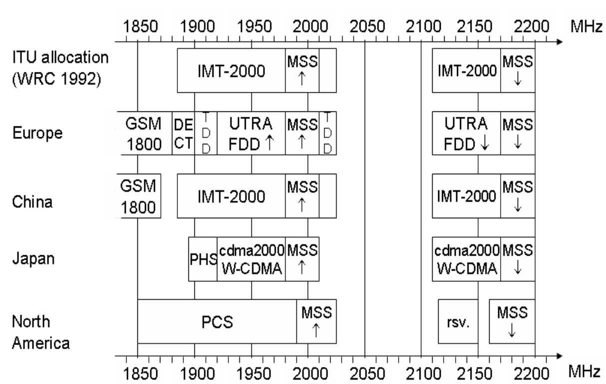

Fig. 4: Frequencies for IMT - 2000

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, 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) 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 and by the Association of Radio Industries and Businesses (ARIB) in Japan. 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).

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.

V. 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) for mobile applications, content conversions from wired to wireless networks, among others.

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.

Thus mobile wireless device is characterized by four constraints:

- **Mobile elements are resource-poor relative to static elements:** For a given cost and level of technology, considerations of weight, power, size & ergonomics will exact a penalty in computational resources such as processor speed, memory size, and disk capacity. Mobile elements will always be resource-poor relative to static elements.
- **Mobility is inherently hazardous:** A stockbroker is more mugged on the streets and has his laptop stolen than to have his workstation in a locked office be physically subverted. In addition to security concerns, portable computers are more vulnerable to loss or damage.
- **Mobile connectivity is highly variable in performance and reliability:** Some buildings may offer reliable, high-bandwidth wireless connectivity while others may only offer low-bandwidth connectivity. Outdoors, a mobile client may have to rely on a low-bandwidth wireless network with gaps in coverage.
- **Mobile elements rely on a finite energy source:** While battery technology will undoubtedly improve over time, the need to be sensitive to power consumption will not diminish. Concern for power consumption must span many levels of hardware and software to be fully effective.

These constraints are not artifacts of current technology, but are essential to mobility. Together, they complicate the design of mobile information systems and require us to rethink traditional approaches to information access.

VI. 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. We have to addresses the issue of power control in wireless data networks as opposed to voice networks and take a game theoretic approach to the problem of assigning transmitter powers to users of error sensitive data applications.

A. 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 Palm-Pilot 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.

B. 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. A number of initiatives attempt to address the problem of formatting web sites and other electronic information for transfer onto current mobile devices. 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.

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.

C. 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 resynchronization are placed in a new light as access speeds, the intensity of handoffs, and the heterogeneity of networks increases.

D. 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 JMT-2000 operators do not want to have to discard their entire 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.

E. 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 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.

VII. So what is a 'Pervasive Computing'?

Pervasive computing, refers to the emerging trend toward numerous, easily accessible computing devices connected to an increasingly ubiquitous network infrastructure. Pervasive computing aims to make our lives simpler through the use of tools that allow us to manage information easily. These "tools" are a new class of intelligent, portable devices that allow the user to plug into powerful networks and gain direct, simple, and secure access to both relevant information and services. Pervasive computing devices are not personal computers as we tend to think of them, but very tiny - even invisible - devices, either mobile or embedded in almost any type of object imaginable; all communicating through increasingly interconnected networks. Information instantly accessible anywhere and anytime is what Pervasive Computing is all about!

A. What's the difference between traditional networking & pervasive computing?

These connections are fundamentally unlike those we associate with networks. Rather than using the network to connect computers that are being used directly by people, these appliances communicate over networks such that people do not directly monitor the communication between machines and programs. The majority of these communications will occur in an end-to-end structure that does not include a human at any point.

The kinds of devices that will be used to access the Internet are no longer confined to desktops and servers, but include small devices with limited user interface facilities (such as cell phones and PDAs); wireless devices with limited bandwidth, computing power, and electrical power; and embedded processors with severe limitations on the amount of memory and computing power available to them. Many of these devices are mobile, changing not only geographic position, but also their place in the topology of the network.

Unlike traditional Desktop Computers and existing networks, the new devices will have the following characteristics:

- Many will have small, inexpensive processors with limited memory and little or no persistent storage.
- They will connect to other computing elements without the direct intervention of users.
- Often, they will be connected by wireless networks.
- They will change rapidly, sometimes by being mobile, sometimes by going on and offline at widely varying rates. Over time, they will be replaced (or fail) far more rapidly than is now common.
- They will be used as a source of information, often sending that information into the center of the network to which they are attached.

B. The advantages of Pervasive Computing

Pervasive computing gives us the tools to manage information quickly, efficiently, and effortlessly. It aims to enable people to accomplish an increasing number of personal and professional transactions using a new class of intelligent and portable appliances or "smart devices" embedded with microprocessors that allow users to plug into intelligent networks and gain direct, simple, and secure access to both relevant information and services. It gives people convenient access to relevant information stored on powerful networks, allowing them to easily take action anywhere, anytime.

Pervasive computing simplifies life by combining open standards-based applications with everyday activities. It removes the complexity of new technologies, enables us to be more efficient in our work and leaves us more leisure time and thus pervasive computing is fast becoming a part of everyday life.

C. What is this next generation going to look like?

As we move to a world where the Internet is used as an infrastructure for embedded computing, all this will change. We can hypothesize that the individual utility of mobile communication, wireless appliances and the respective mobile services - pervasive technologies in general - will be exploited through a digital environment that is –

- Aware of their presence
- Sensitive, adaptive and responsive to their needs, habits and emotions and
- Ubiquitously accessible via natural interaction.

Increasingly, many of the chips around us will sense their environment in rudimentary but effective ways. For Example –

- Cell phones will ask the landline phone what its telephone number is and will forward our calls to it.
- Remote computers will monitor our health statistics and will determine when one is in trouble and will take appropriate action for rescue.
- Amplifiers will be implanted and used in the inner ear.
- New machines that scan, probe, penetrate and enhance our bodies will be used.
- Refrigerators will be connected to the Internet so one could find out, via cell phone or PDA, what is in it while one is at the store. A refrigerator may even sense when it is low on milk and order more directly from the supplier or rather than this, the connection will enable the manufacturer to monitor the appliance directly to ensure that it is working correctly and inform the owner when it is not.
- Stoves will conspire with the refrigerators to decide what recipe makes the best use of the available ingredients, then guide us through preparation of the recipe with the aid of a network-connected food processor and blender. Or they will communicate to optimize the energy usage in our households.
- Cars will use the Internet to find an open parking space or the nearest vegetarian restaurant for their owners or to allow the manufacturer to diagnose problems before they happen, and either inform the owner of the needed service or automatically install the necessary (software) repair.
- and many more……

In a nutshell, our personal network will travel around with us like a surrounding bubble, connecting to the environment through which we move and allowing our mobile tools to provide us with more functionality than they ever could alone.

VIII. Conclusion

The tension between autonomy and interdependence is intrinsic to all distributed systems. Mobility exacerbates this tension, making it necessary for mobile clients to tolerate a far broader range of external conditions than has been necessary hitherto. Adaptation is the key to mobility. Mobility will influence the evolution of distributed systems in ways that we can only dimly perceive at the present time. In this sense, mobile computing is truly a seminal influence on the design of distributed systems.

With the impending implementation of IMT-2000 systems, the next generation of cellular systems shows promises in advancing the status mobile computing significantly. Access speeds approaching 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 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 smart phones. 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.

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 any media 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.

Pervasive computing provides an attractive vision for the future of computing. Well, we no longer will be sitting down in front of a PC to get access to information. In this wireless world we will have instant access to the information and services that we will want to access with devices, such as Smart phones, PDAs, set-top boxes, embedded intelligence in your automobile and others, all linked to the network, allowing us to connect anytime, anywhere seamlessly, and very importantly, transparently. Computational power will be available everywhere through mobile and stationary devices that will dynamically connect and coordinate to smoothly help users in accomplishing their tasks.

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