Driving Forces in Wireless Data Communications

Ron A. Haberkorn, Ph.D. and Paul E. Nikolich

Dr. Ron Haberkorn, a principal engineer at Steinbrecher Corporation, is working on the design of a public indoor microcell cellular base station. Before joining Steinbrecher, he initiated a wireless communications program at Racal Datacom, Inc. He spent several years at Mitre Corporation where he headed up the Advanced EHF Satellite Terminals project. From 1980 to 1985, Dr. Haberkorn was at the Francis Bitter National Magnet Laboratory at MIT where he helped set up the Magnetic Resonance Imaging (MRI) Center. Dr. Haberkorn received his Ph.D. from MIT for his thesis on solid state nuclear magnetic resonance (NMR) spectroscopy. He completed an MSEE degree from Boston University in Communications and Signal Processing

Mr. Paul Nikolich is an advisory member of technical staff responsible for Advanced Technology Development for Racal Datacom. He has over 15 years experience in the communications industry developing technologies, products, and standards. His interests are focused on the development of emerging local loop access technologies such as wireless, high bit rate subscriber lines, and, most recently, CATV modems and their interface to customer premise LANs. He is actively involved in the establishment of LAN data communications standards as the vice-chair of the 802.3 (Ethernet) working group of the IEEE's Project 802. Mr. Nikolich received his B.S. and M.S. degrees in engineering from Polytechnic University in Brooklyn, New York.

The objective of this paper is to present an overview of the driving forces which affect the wireless data communications industry. This effort will concentrate on several applications and relate them to some sample markets. The market driving forces will be identified and discussed. This work will focus on wide area network (WAN) applications for which wireless data communications provide suitable solutions. In particular, this article will concentrate on terrestrial radio-based systems and will only touch briefly on satellite systems.

The field of wireless data communications is very broad and, in the short space available, only a very small segment can be adequately addressed. As a result, local area networks (LANs), while a significant market in their own right, cannot be addressed. It is hoped that this article will provide a concise yet thorough overview of the WAN market and the corresponding forces which are shaping its future, particularly in the United States.

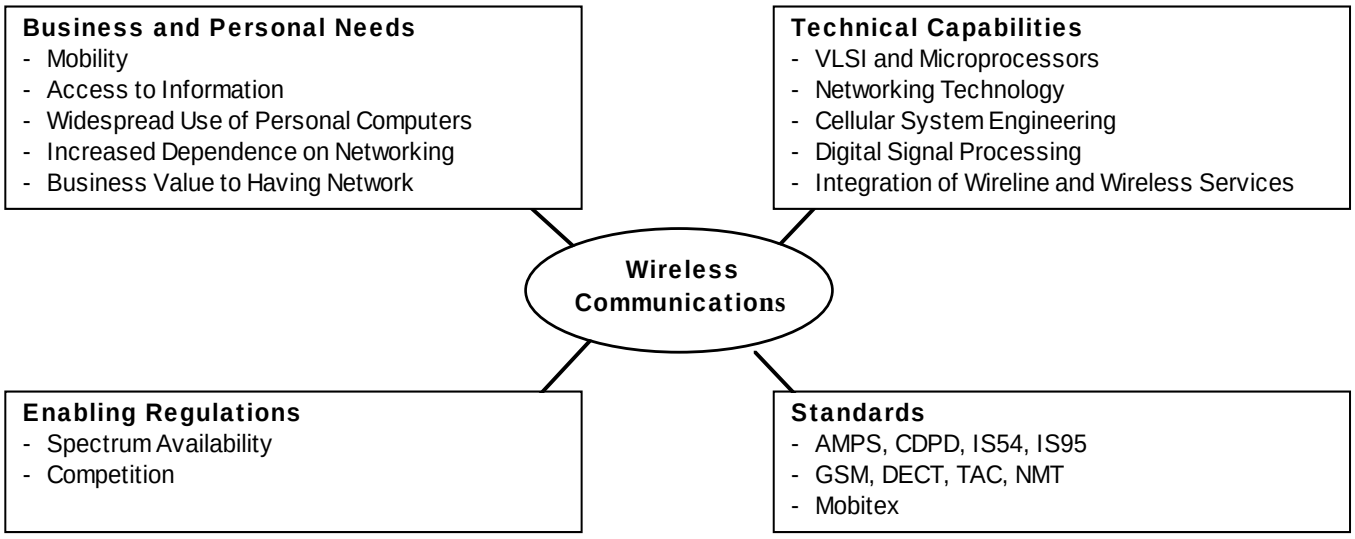
We will first put this work in context by presenting a general overview of wireless communications. This will include an overview of the technologies which enable the services and equipment features that satisfy end-user requirements. The regulatory and standards environment will be discussed next, as it is a fundamental force which defines many of the services which can be made available to the end users.

A general market profile will be presented which will include a discussion of several major applications for wireless data communications technology. Some examples of significant industries which can make use of these applications will be discussed and characterized. The market will be further characterized in terms of the equipment and service providers. The capabilities delivered to the end users is highly dependent on the types of services available, as well as the equipment needed to implement these services.

Finally, the future trends in the market will be summarized, and the forces which seem to be shaping it will be identified and discussed.

The wireless data communications market has been shaped by a number of independent forces (shown in Figure 1) which have come together to form the market as we know it today. These forces will continue to operate and will affect the market to differing degrees in the future. First and foremost, there exists an end-user community which has both

Figure 1
Summary of Key Requirements, Enabling Technologies, and Regulatory and Standards Environments for Wireless Communications



Source: Haberkorn & Nikolich

business and personal needs for untethered communications. This community has arisen because of the almost ubiquitous reliance on personal computers for almost all aspects of business life, as well as an increase in the use of the PCs at home for everything from maintaining personal finances to education and entertainment. The increased sophistication of the data communications between computers has made many tasks trivial and even automatic, tasks which were, only a few years ago, laborious and demanding of a great deal of precision. This has led to similar applications being carried farther and farther afield, with the net result that the end users are demanding networked capabilities away from the office as well. The demands for this increased mobility now require a tetherless connection for much of the communications.

The technologies which have enabled manufacturers to realize these capabilities are the same technologies that have driven the computer and communications industries for the past several decades. These include advances in Very Large Scale Integration (VLSI), microprocessors, digital signal processing, and networking protocols and software as well as new developments in cellular radio system engineering. In addition, the integration of wireless communications with the Public Switched Telephone Network (PSTN) and the development of methods for sending data over this medium are just now starting to evolve. This will lead to explosive growth in the use of wireless networks for data communications as part of the widespread usage of copper, fiber, and wireless media for the delivery of data and telephone services in developed countries.

With the deregulation of the telephone industry, in particular in the United States, and because of increasing demand for wireless data services, regulators have had to develop regulations which encouraged and even mandated a competitive environment as new spectrum was allocated for these services. In addition, new standards are being developed which will further encourage competition for services. However, in some areas, such as the United States for example, the proliferation of standards and proposed standards has caused some consumer confusion with a resultant damping effect on the market. In Europe, the Global System for Mobile Communications (GSM) standard should have the opposite effect and increase the market.

Wireless Communications Overview

Figure 2 illustrates an overview of the various wireless services either currently available or planned for the near future. These services can be broadly classified into two groups based on whether or not the

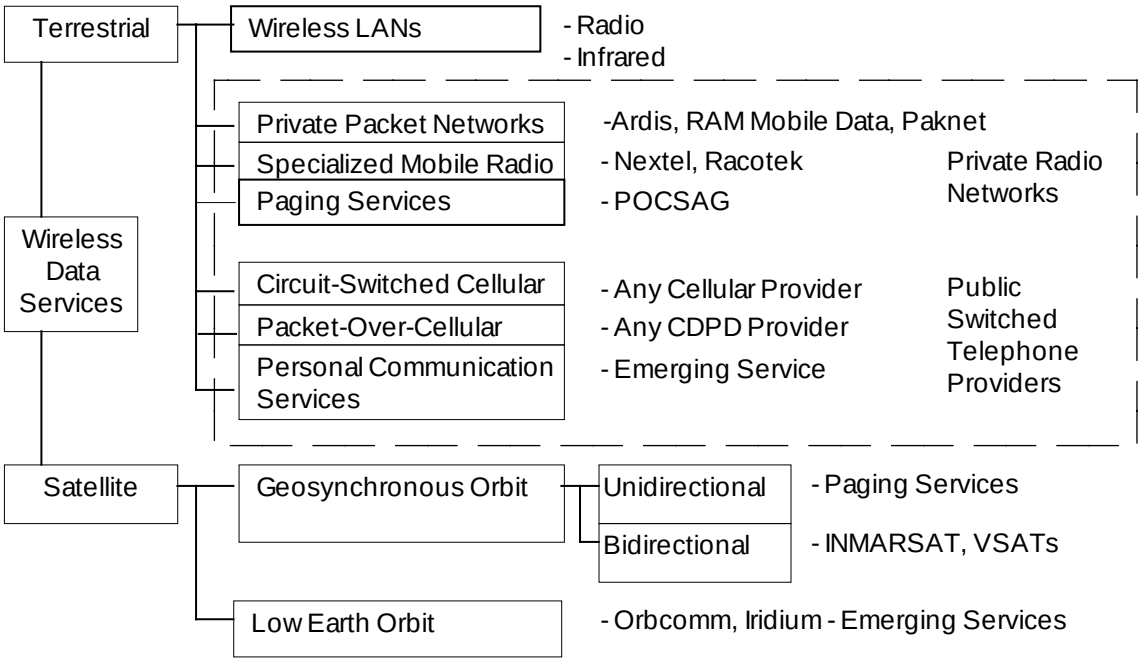
services are provided by satellite. Satellite services are generally provided by spacecraft in geosynchronous orbit. These consist of most of the wide area paging services as well as the INMARSAT and VSAT type of services. In addition, there are all the broadcast and telephone trunking services which are currently provided. Low earth orbit satellites are just now starting to be fielded, and they will certainly provide some interesting communications services.

There are a number of providers of wireless local area networking (LAN) equipment that end users buy and operate. These systems generally have ranges of less than 500 feet and are generally confined to small areas such as buildings. The data rates obtainable from these systems are typically much higher than the wide area network systems; certain implementations attain bit rates in excess of one Mb/s.

The wide area services can be divided into two sectors which have different forces operating on them. Private radio networks operate in a non-cellular environment. Therefore, without the high degree of spectrum reuse typical in cellular systems, private radio networks do not have the ability to accommodate the large number of users that the cellular systems can. The forces operating on private radio systems are different than public radio systems such as cellular. For example, the initial fixed cost is important when considering investing in a private system, whereas operating cost dominates the cellular investment analysis.

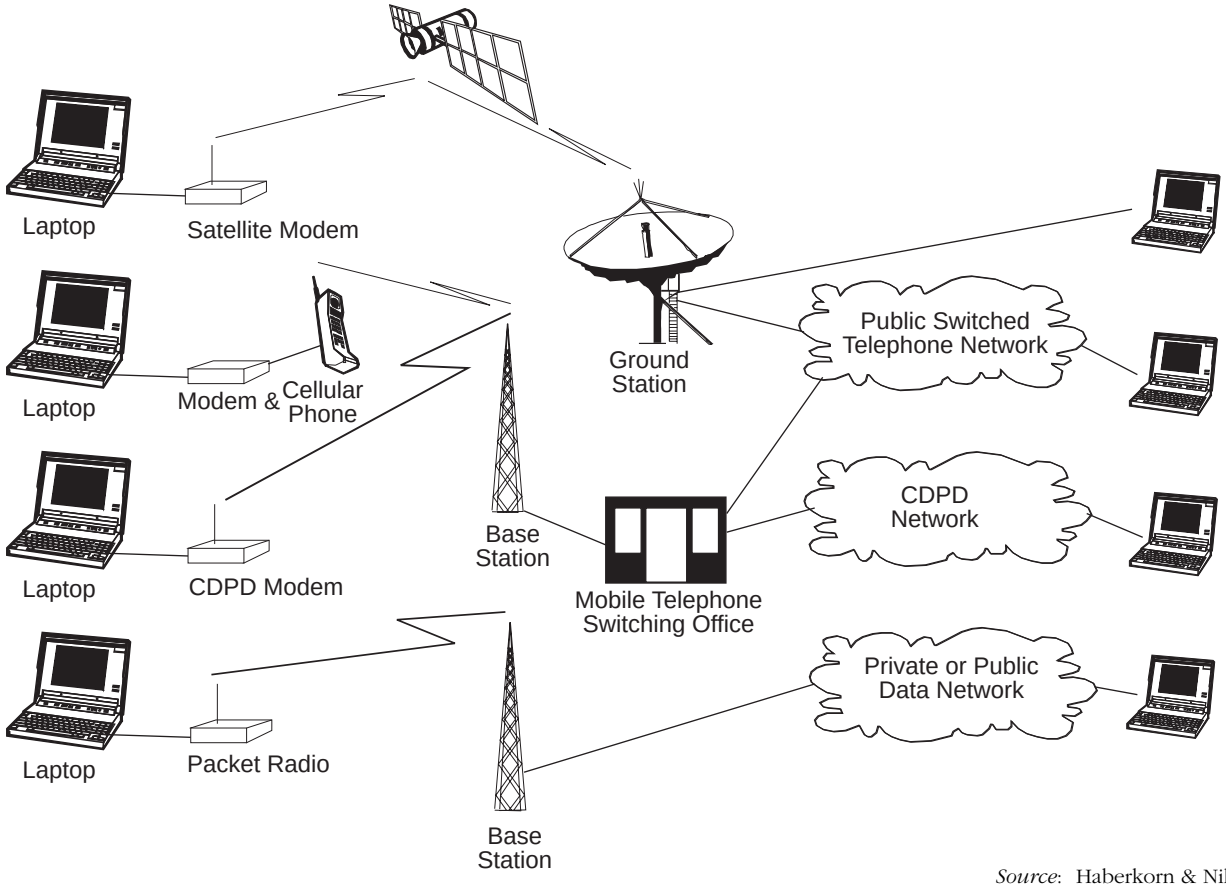
In Figure 3, an overview of the infrastructure needed for wireless data communications is shown. Common to each of the technologies is the requirement for a modem capable of broadcasting at the appropriate frequencies. For the case of cellular infrastructure, protocols used with these modems must be capable of accommodating the frequent signal drop-outs which are experienced on these channels with a mobile platform. The cellular phone communicates with the base station, which is connected to the mobile telephone switching office (MTSO) via wire line. These MTSOs are responsible for managing the connections with the base stations and for the connection to the PSTN. Cellular Digital Packet Data (CDPD) systems operate similarly except that, since this is a

Figure 2
Overview of Wireless Data Communication Services



Source: Haberkorn & Nikolich

Figure 3
Overview of Wireless Data Communication Infrastructure



Source: Haberkorn & Nikolich

packet protocol, the data is handled differently at the MTSO than normal voice cellular signal.

The packet radio services such as Ardis and RAM Mobile Data require that the appropriate modem is attached to the portable computer or other data device so that the air link can be established to the base station. The data routing is then accomplished over the service provider's data network, and the data is delivered to the customer's end site. Satellite communications operate in much the same way except that the satellite serves as an intermediate relay point. In the case of INMARSAT, connection can then be made to the PSTN. Other satellite systems can go directly to the user equipment from the ground station.

Regulatory/Standards Environment

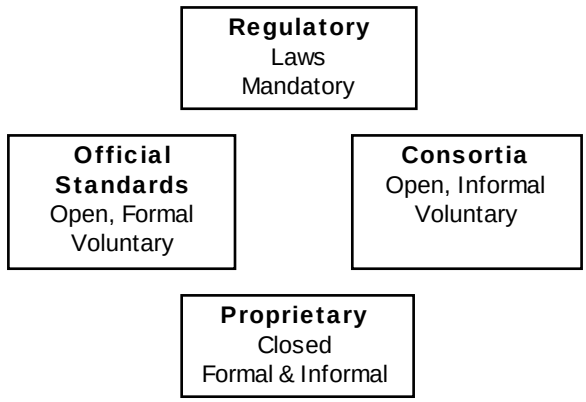
The regulatory environment is governed by the four basic classes of standards and regulations as shown in Figure 4.

Regulatory

The national and international regulatory bodies (ITU–R Radio Regulation Board) have the biggest effect on the wireless market for WANs. The laws and regulations which are put in place by these organizations are mandatory, and failure of a service provider to adhere to them can result in punitive sanctions. These bodies allocate the radio spectrum which must be used and regulate the operational parameters such as power limits, bandwidth, etc. These are the basic resources for wireless data communications, and they define fundamental limits on the capabilities of the system such as capacity, data rates, and channel availability, as well as the growth of the systems.

The current trend by many regulatory agencies, such as the Federal Communications Commission (FCC) in the United States, is toward allocating spectrum in such a way as to encourage or even mandate

Figure 4
Four Classes of Standards and Regulations



Source: Haberkorn & Nikolich

competition for wireless services. This has had a beneficial effect for the consumer in that pricing for analog cellular services has become very reasonable. The biggest disadvantage is that, because of the intense pricing pressures, service providers will most likely not be profitable for many years until there is a much larger customer base.

The spectrum allocated for cellular telephony and packet radio in the United States is in the 800 MHz to 1,000 MHz radio band. To encourage competition, the FCC has divided the cellular spectrum into an "A" spectrum and a "B" spectrum. The same service provider is not allowed to have a license for both the A and B spectra in the same trading area. Therefore, the FCC has guaranteed that, for every trading area, there will be two service providers for cellular telephony using a common standard.

The 1,850 MHz to 2,200 MHz band has been allocated for Personal Communication Services (PCS) and is currently being auctioned off in the United States by the FCC. Similar rules will apply to this band to ensure that there are multiple service providers in each service area. However, the FCC has not mandated any standard, preferring instead to let the marketplace decide on the most advantageous technique.

The magnitude of the radiated power is also limited by the regulatory agencies for both safety reasons as well as to control the interference between neighboring transmitters. Power constraints have the effect of limiting the maximum data rates as well as the distance from the base station over which effective communications can take place. These factors directly affect the number of base stations required as well as the number of subscribers and the data throughput which can be supported.

Official Standards

The purpose of the various national and international standards bodies such as the International Standards Organization (ISO) or the International Telecommunication Union (ITU) is to sanction the various standards which guarantee the interoperability of equipment regardless of manufacturing origin. These standards are publicly-available formal documents, but generally adherence to them is voluntary. In many cases, it is the consumer who demands adherence to these standards in order to be able to use his equipment among several service providers. Examples of these types of standards published in the United States under the auspices of the American National Standards Institute's (ANSI) Telecommunications Industry Association (TIA) body are:

- The Advanced Mobile Phone Service (AMPS) standard for cellular service.
- The Time Division Multiple Access (TDMA) standard, IS54.
- The Code Division Multiple Access (CDMA) standard, IS95.

In Europe, an example of this is the GSM standard for digital cellular telephony. Formal standards are continually being developed, e.g., the Joint Technical Committee (JTC) PCS air interface standards currently in development in the United States.

Consortia

Consortia are formed by groups of equipment or service providers and generate open standards not sanctioned by any of the standards organizations. Therefore, these standards are informal documents and adherence is voluntary. Once again, the consumer is the main driving force for adherence to these standards. Examples of these types of standards are the Cellular Digital Packet Data (CDPD) standard which was generated by the CDPD Forum or the Mobitex standard which is maintained by the Mobitex Operators Association.

Proprietary

Proprietary implementations are generally not publicly available, but are developed and maintained by equipment or service providers. This type of

standard is more prevalent in the wireless LAN arena where the customers are not so concerned with interoperability of equipment from many manufacturers. These systems operate within the allocated radio spectrum and within the prescribed limits of power, bandwidth, etc.

Market Forces

According to John Mazzaferro of JAM Enterprizes, the size of the wireless data communications market is currently at about $2 billion in total revenues. It is expected to grow at greater than 50% per year and is expected to reach over $7.8 billion by the year 1999. This includes the revenues from all data services and equipment, including satellite revenues which is about 25% of this market. Other market surveys predict anywhere from a factor of three to six growth in the wireless communications market by the year 2000 from the 1993-1994 levels. Another observation which indicates that the wireless market is poised for an explosive growth is the fact that, in the United States, there were more new cellular subscriber lines initiated than wire subscriber lines in 1993. The question now is what forces will shape the future of this industry.

The wireless data communications market can be broadly divided into four segments:

- End users.
- Equipment manufacturers.
- Service providers.
- System integrators.

In many cases, a single company may perform the functions of several segments. Each of the segments has their own unique set of driving forces.

End Users

Each of these segments is highly interdependent but, ultimately, the end users' needs must be satisfied at an affordable price in order for the market to develop successfully. The principle requirements which must be met to satisfy the end user's needs are:

- Coverage.
- Convenience.
- Capacity (number of users).
- Cost.
- Reliability.
- Speed.
- Security.
- Safety.

The issues related to each of these requirements are heavily dependent on the type of application the end user is trying to implement. These applications can be classified into the following broad categories:

- Electronic Messaging and Dispatch.
- Transaction Processing.
- Remote Data Access.
- Remote Monitoring.

Table 1 attempts to map these market types into various vertical markets and to identify the key end user requirements which will drive the use of wireless communications for these applications.

Electronic Messaging and Dispatch. Typical markets for this application are messaging and paging services, as well as dispatching service personnel such as field service or package delivery services. Characteristic of these applications is the need for personnel in the field to receive small amounts of information periodically such as service call assignments, rerouting instructions, etc. In some applications, the area which needs to be covered is extremely large, spanning continents or oceans, and for these cases, satellite networks are usually the most logical choice. However, the messaging and dispatch applications still account for almost half of the cellular and the packet radio markets.

Transaction Processing. This market centers around applications such as easily relocatable point-of-sale terminals where the terminal accesses a central database in frequent short messages to complete a transaction such as credit card verification. For these applications, security is one major consideration. The applications themselves are usually routine and therefore lend themselves to a high degree of automation. This results in a simple convenient user interface. Systems such as the Paknet X.25 Radio Data Network are needed to satisfy these requirements.

Remote Data Access. The market for the remote data access application is field service personnel who need access to databases of repair manuals, the executive who demands access to his office computer while on travel, etc. This is a major growth area for wireless communications, as the technology and infrastructure are just now reaching a level of maturity to support these markets The utility of these applications is the access provided to the personnel to very large databases and timely access to databases that have frequently-changing information. In addition, there is growing interest in leveraging the skills of

Table 1
Comparison of Market Types, Vertical Markets, and End User Requirements

Market Types	Vertical Markets	End User Requirements
Electronic Messaging and Dispatch	Field Service Emergency Services Package Delivery Services Shipping Trucking	Low Data Rate Low Duty Cycle Wide Coverage Area Convenient to Use Reasonable Cost
Transaction Processing	Point-of-Sale Credit Card Verification Banking Toll Collection	Small Amount of Data per Transaction Infrequent Access High Security is Mandatory Convenient to Use Low Cost
Remote Data Access	Telemedicine Executive Field Service Sales Insurance Adjusters Real Estate	Fast Data Transfer Send/Receive Images Access to Repair Manuals/Documentation Access Price/Availability Data Place Orders at Customers' Site Convenience is Major Issue Reasonable Cost
Remote Monitoring	Traffic Pipeline Utility Meters	Low Data Rate per Site Potentially Large Number of Sites Essentially One-Way Communications Large Coverage Area Low Cost

Source: Haberkorn & Nikolich

highly-trained personnel at remote locations such as in telemedicine. In this case, even imagery will be transmitted from the remote location. This is a severe technical constraint as the power which can be transmitted must be limited for safety and interference reasons, and therefore the distance will be limited.

Remote Monitoring. Remote monitoring applications have typically infrequent, low data throughput requirements but are difficult to access. Examples of this are pipeline monitoring, gas and electric meter reading, etc. The monitoring of sites located in remote access environments is probably best addressed by satellite technology; however, even within urban environments, there could be efficiencies obtained by monitoring utility meters at homes via a wireless network. The principal driving force for this application will be the cost of the equipment compared with the cost of personnel or the tariff structure of the local public phone carrier.

Equipment Providers

As can be seen from Figure 3, for the wireless system to be useful and operate properly, several types of equipment must be in place together with the associated application software. The manufacturers of these items can be broadly classified into three classes:

(1) Base Station/MTSO Equipment.
(2) End User Equipment.
(3) Application Software.

The base station and MTSO contain all the equipment needed to communicate with the end user and to

perform the switching functions needed to route the data to the other wireless users or to the wireline infrastructure. This equipment represents the largest investment that a service provider must make in order to provide wireless communications services. As the coverage area is increased or additional subscribers are added, in general, more equipment must be purchased and the costs recovered through user fees. For a private radio network, a single user shoulders the entire burden of this cost for his service. The cost of this equipment is a significant driving force behind the development of new protocols which either allow the use of less expensive equipment and/or allow the same equipment to accommodate more subscribers.

A good example of this is in the United States, where cellular carriers are considering the use of two digital alternatives to the current AMPS system. These are the TDMA standard and the CDMA standard. The predictions for TDMA indicate that, for a very modest investment, a single AMPS channel can accommodate at least three times the number of subscribers and perhaps as many as 10 times the number. Similarly, CDMA proponents are making claims of at least a 10- to 20-fold increase in the number of subscribers that can be supported. Each system is currently being tested in various areas of the United States, and the results will certainly influence the purchase of large amounts of equipment. In addition, the emerging PCS broadband CDMA market will offer further opportunities for equipment vendors, as an entire infrastructure still has to be built.

The trend in end-user equipment is for smaller, lighter weight for ease of carrying, better power efficiency for longer battery life, and lighter weight batteries, as well as easy push-button operation. In addition, the trend is toward higher levels of integration of all end user equipment. For example, by the turn of the century, laptop computers will doubtless have integrated wireless modems which can be used on several systems. Many pundits have predicted that the personal digital assistant will become ubiquitous and will include all personal communications, both data and voice, integrated in a single pocket-size unit. Whether or not this level of integration is ever achieved, it is certainly true that end users will only use wireless data communication if it is convenient and useful. This means that a significant driving force for the use of wireless data communications is to have a well-integrated solution for whatever data device is needed for the particular application.

Service Providers

As indicated in Figure 2, service providers fall into two main categories: cellular services providers and packet radio network providers. The packet radio network providers, for the purpose of this discussion, are the system operators like Ardis and RAM Mobile Data. This distinction is more historical at present since cellular providers are also beginning to offer packet services. Ardis and RAM Mobile Data each own a portion of the spectrum in the United States, and they have optimized their systems and pricing structures to satisfy end users with short bursty communications requirements.

Cellular providers, however, based their data services on circuit switch techniques as this fit in well with their voice service offerings. With the increased interest among end users for wireless data and the anticipated explosive growth of this market, cellular providers are adapting their systems to more easily accommodate data communications in a cost-effective manner.

CDPD efforts are geared to transferring data in a packetized manner over the existing AMPS infrastructure, and this will certainly compete directly with private radio network operators. In addition, there have been some discussions to incorporate data service features in the new TDMA and CDMA standards. This could have the effect of taking customers away from private radio network providers. This is a key driving force for cellular data communications, as it will significantly impact the rate structure which the cellular service providers must establish in a way that will make it more cost effective for the end user.

System Integrators

Certainly in the near term, a system integration facilitator will be a necessity for the end user. The market for wireless data services at the present time is very confusing, and the integration of the end user's application with the wireless service is not straightforward. The extent to which this is provided by service providers and equipment manufacturers or software developers will greatly affect the rate at which wireless services are adopted by the end users.

Summary

The market forces driving the expansion of the wireless data communication industry are ultimately the end users' desires to make their organizations more efficient and to offer new or enhanced services

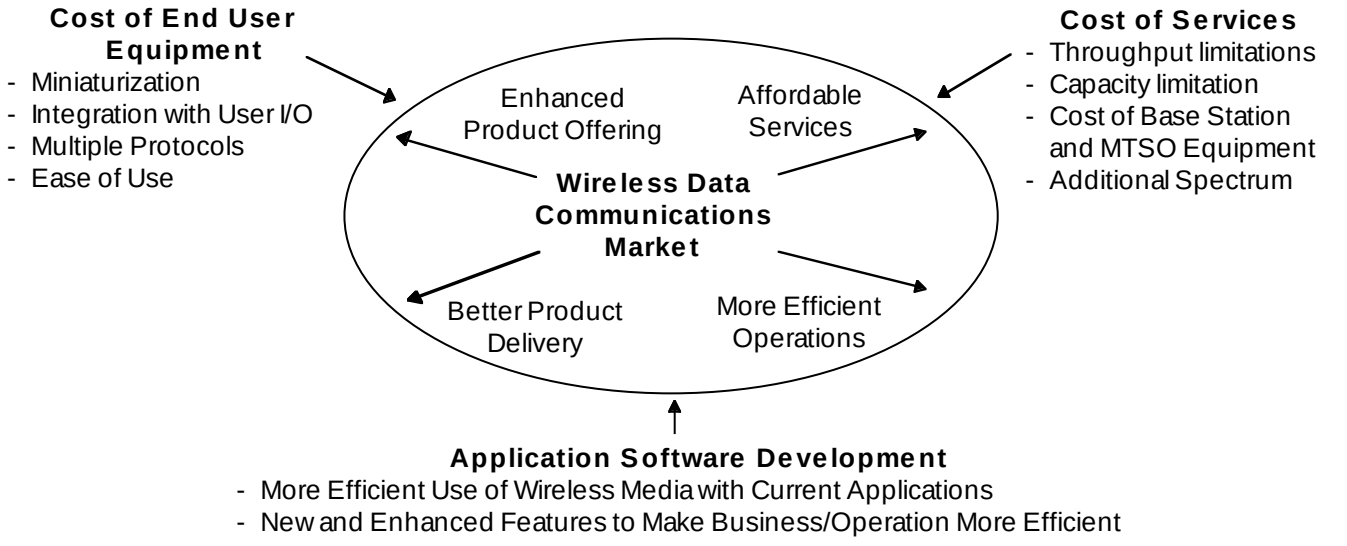
for the lowest price possible. As illustrated in Figure 5, the market is expanding because end users see opportunities to make their own product offerings more efficient, to expand into new areas with enhanced products, and to make better use of their personnel for more efficient operation. The opposing forces are the high cost of equipment, the limited resources of the radio spectrum, the cost of providing these services, and the pace at which new application software can be written or existing application software can be modified to take advantage of wireless communications media. For example, as the cost of equipment and service is decreased, the market will expand as it becomes more cost effective to deliver new and enhanced services.

The driving forces which will reduce the cost of services are affected by current efforts to increase the capacity of the systems through more efficient use of spectrum (i.e., TDMA, CDMA, and CDPD development efforts), decreasing the costs associated with the purchase and operation of the base station and MTSO equipment, as well as the increased amount of spectrum which is becoming available (i.e., the PCS spectrum auctions now occurring in the United States). One force which may be impeding the market expansion in the United States is the number of protocols currently under development. This will cause consumer confusion and will also require, at least for the near term, different modems depending on what service area the user is in.

The cost of end-user equipment will continue to decline as the applications become better defined. This will occur through the use of higher levels of integration, and the ability to adapt to multiple protocols. Also, as the market expands, the cost of equipment will be further reduced due to increased production volume. Initially, the multiple protocols will be a hindrance, but eventually modems will be developed that will be able to transparently adapt to whatever protocol is supported by the service provider in the area.

Applications programs are potentially the biggest driver. These will ultimately define the degree to which wireless data communications are useful to the end user. In particular, there will doubtless be one "killer application" which causes rapid market expansion. The result of this will be to make it cost effective for other applications to take advantage of the wireless media, further increasing the market. There has been much speculation on what this "killer" application will be, yet, to date, it remains to be defined. ntq

Figure 5
Wireless Data Communication Market Forces



Source: Haberkorn & Nikolich