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THESIS

WIRELESS APPLICATIONS FOR MARINE AIR GROUND TASK FORCES

by

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June, 1996

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of the requirements for the degree of

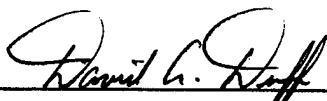
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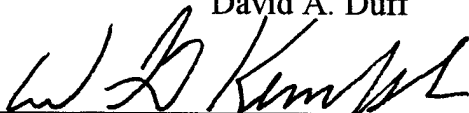
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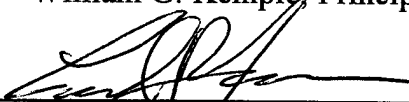


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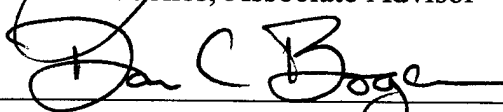
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ABSTRACT

Wireless telecommunications have a place in the Marine Corps' future. The challenge is finding ways to match Marine Corps needs with current and future digital wireless technologies. The advanced command and coordination concepts envisioned for future expeditionary operations mesh well with technologies explored in this study. These include cellular networks, wireless data networks, mobile satellite services, and personal communication services. Careful application of these technologies will improve Marine command and coordination efforts in dynamic environments. Instead of physical connections offering information exchange from place-to-place, wireless methods offer true "person-to-person" information exchange, regardless of location. On the chaotic, unstructured battlefields of the next ten to twenty years, getting key information to specific people, as opposed to places, will be even more important than it is now. There are a number of Marine personnel, processes, and applications at the MAGTF that could benefit from commercially available wireless technologies.

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EXECUTIVE SUMMARY

Recent advances in digital signal processing and integrated circuit power have driven tremendous surges in the development of wireless communications products, services, and networks. As the nation's force in readiness, the Marine Corps is tasked to operate combined-arms forces that are highly trained, forward-deployed, and well equipped. It seems clear that wireless applications have a place in the Marine Corps. The challenge is finding ways to match the needs of the Marine Corps with the current and future digital wireless technologies. Fundamentally, the Marine Corps must examine its future needs and compare them to the new wireless technologies that are taking the commercial world by storm. The importance and frequency of military operations other than war requiring Marine Corps participation has increased. For these challenging environments and missions, new ways to move information, independent of tethered connections, must be leveraged.

New wireless technologies explored in this study will allow enormous jumps in the number, quality, and type of services available to Marines at the battalion level. These include, but are not limited to:

1. Worldwide connectivity via commercial networks.
2. Small, lightweight, low-power devices that are easy to use and carry.

3. *Personal* communications capability, as opposed to *unit* communications capability.

4. The capability for any Marine to send and receive voice, data, imagery, position, and targeting data to any other Marine in the hierarchy quickly, reliably, securely, and easily.

The reader is first familiarized with the operation, architecture, and use of cellular telephony. A brief description of the history of cellular is presented. Following this, basic cellular architecture is introduced including concepts of frequency re-use, cell handoff, and cell splitting. A typical cellular telephone call is described for illustration. A brief description of modern digital cellular networks, like Global System for Mobile communications (GSM), follows. Inherent advantages and disadvantages of cellular telephones are discussed in the context of military use.

Large-scale, wide-area data networks are described. Also, recent small-scale wireless LAN products available today are reviewed.

Next, Personal Communications Services are covered. These new networks have immense potential for military use. International terrestrial systems, as well as proposed space-based services are outlined.

Following this, areas where wireless devices, networks, or services could enhance command and control for Marine Air Ground Task Forces are highlighted. First, the MAGTF is defined, and key ideas behind this organization are presented. Next, SEA

DRAGON, an advanced concept for naval expeditionary warfare, is discussed, with emphasis on where wireless technology insertion offers good solutions. Following this, the author briefly presents some applications that could benefit our warfighters today.

The following conclusions are offered in regard to Marine Corps employment of wireless technologies:

1. There are a number of Marine personnel, processes, and applications at the MAGTF that could benefit from commercially available wireless technologies.

2. The small size, low power, and cheap cost of new wireless devices will allow their easy introduction to the lowest levels in the hierarchy.

3. Future warfighting concepts like SEA DRAGON will be well supported by the envisioned capabilities of a mature, global Personal Communications Network.

I. INTRODUCTION

A. OPPORTUNITIES

Recent advances in wireless telecommunications technologies have ignited the imaginations of many. The explosive growth of cellular phone use in the private sector and the business world has outpaced any previous estimate. In the US alone, 32 million people use a cellular phone to communicate [Ref. 1]. Pagers now send and receive small text messages for people who move around constantly during the workday. Cordless telephones have become very popular now that voice quality problems are solved. Wireless local area networks (LANs) are being used in industry and government for many varied applications. Finally, personal communications services, which encompass some of the above technologies, are making the dream of ubiquitous communications a reality.

As the nation's force in readiness, the Marine Corps is tasked to operate combined-arms forces that are highly trained, forward-deployed, and well-equipped. It seems clear that wireless applications have a place in the Marine Corps. The challenge is finding ways to match the needs of the Marine Corps with the current and future digital wireless technologies. That is, what needs of a Marine, as part of any element of a Marine Air Ground Task Force, would best be met by a cellular phone? What advantages are offered by commercial technologies today that could augment and enhance the systems the Marine Corps operates now?

Fundamentally, the Marine Corps must examine its future needs and compare them to the new wireless technologies that are taking the commercial world by storm. SEA DRAGON, a new vision for how naval expeditionary forces will fight in the 21st Century, has been presented by

Marine Corps leadership to industry this year [Ref. 2]. The advanced command and coordination concepts envisioned for SEA DRAGON mesh well with the technologies explored in this study. These include wireless data networks, mobile satellite services, and personal communication services. The benefits offered by careful application of these technologies will improve the commander's ability to command and coordinate. That means improved combat effectiveness.

B. PARADIGM SHIFT

The 20th century saw telecommunications companies assemble tremendous networks of copper wire. The wire connections from our homes, places of work, and public places led to telephone company central office switches. These switches were connected by inter-exchange links of larger capacity. These links have become so large that fiber optic cables, with their great capacity, are now the medium of choice. The whole idea behind the wired infrastructure was to make data and voice communications available in *places*. People needed to be in these places to take advantage of these information exchange capabilities. But, rapid changes in business practices, work habits, and even warfighting have made personal mobility crucial. People must now be able to move away from their traditional wired work environments and still retain their information exchange capabilities.

The main advantages of physical connections are security and capacity. These are also compelling reasons for their use in military C4I systems. But, the nature of the environments Marines fight in today calls for more flexible and mobile systems. The types of missions and operations requiring Marine Corps participation have expanded to include disaster relief, humanitarian aid, and military operations other than war. For these challenging environments and

missions, new ways to move information, independent of tethered connections, must be leveraged, without forfeiting security or capacity.

Most voice and data networks at the higher echelons of command in the Marine Corps are based on physical connections. But, at lower echelons, namely, battalion level and below, the primary means of communications is single-channel radio. Although single-channel radio is technically "wireless," it is very limited compared to the new wireless technologies explored in this study. These new technologies will allow enormous improvements in the number, quality, and type of services available to Marines at the battalion level. These include, but are not limited to:

1. Worldwide connectivity via commercial networks.
2. Small, lightweight, low-power devices that are easy to use and carry.
3. *Personal* communications capability, as opposed to *unit* communications capability.
4. The capability for any marine to send and receive voice, data, imagery, position, and targeting data to any other marine in the hierarchy quickly, reliably, securely, and easily.

With the exception of the Marine Corps' single-channel radio, every piece of communications and electronics equipment must be physically connected to a copper wire, shielded twisted-pair, co-axial cable, or fiber optic strand. Even single-channel radio employment by Marines often makes use of wired connections between radio transmission sites and users. This equipment must be moved, installed, operated, and maintained by Marines. This is how the Marine Corps has done it for years, but now there are better ways; wireless opportunities must be explored.

Instead of the physical connections offering information exchange from place-to-place, a wireless model offers true "person-to-person" information exchange, regardless of location. On the chaotic, unstructured battlefields of the next ten to twenty years, getting key information to a specific person, as opposed to a place, will be even more important than it is now. Two important reasons the Marine Corps should explore wireless communications are:

1. These technologies are available commercially today, meaning potential enemies can and will exploit their benefits.
2. Person-to-person information exchange is fast.

For this study, the terms "wireless," and "wireless communications" mean the ability for people to communicate using small, mobile, low-power devices of every description. The overall objective of wireless is to reduce or eliminate cabling requirements while greatly enhancing services to users. In this study, wireless communications will include many different technologies, all of which contribute to the above objectives.

The main reason for growth in wireless telecommunications in the past five years is the ability to create advanced digital signal processing (DSP) integrated chips [Ref. 3]. These can handle many millions of instructions per second. The increased processing power has resulted from the development, through very large scale integration techniques, of chips that can handle digital encoding and decoding, error correction, modulation, and encryption by themselves. Thus, in tiny, cheaply manufactured integrated chips of silicon, or more recently, gallium arsenide, lie many of the basic solutions to traditional communications dilemmas: noise, security, speed, and complexity that are transparent to the user. Second, we have been able to increase the number of users who can access a network at one time. In the past, multiple access

technologies worked with slots of time or slices of frequency to separate users. Multiple access technologies are ways communications engineers "parcel out" the resource of bandwidth to accomodate multiple users on a network. New techniques use pseudo-random noise codes to differentiate users, while using less power and increasing spectral efficiency, which is the real information-carrying value we get from a given frequency bandwidth.

One of the primary advantages offered by wireless technologies is the reduced time it takes to deploy a network in a given place. A mobile cellular base station, for example, can immediately provide reliable, secure, voice and limited data services within a certain geographic area. It needs no cables except those for power, there are no wiring diagrams to draw, and it could greatly reduce the personnel requirements.

Flexibility is another great advantage of wireless. Instead of having to operate where physical connections terminate, the user is able to go where he desires, while still bringing most of the capabilities of the wired network with him. The number of users who use wireless services is increasing because access devices are smaller, lighter, and more convenient to carry. In addition, modern wireless networks can support many users at once.

Speed, flexibility, simplicity, and mobility are some of the main reasons that all military services are looking for innovative and cheaper solutions through wireless. Although some wireless services have been around for decades (single-channel radio), it is the author's opinion that the military can give focus and direction to a new wireless industry.

C. REMAINING CHAPTER SUMMARY

The next three chapters will describe currently available technology in order to establish a common base of knowledge for the reader. The final two chapters will build on this to explore

wireless applicability to Marine Air Ground Task Force (MAGTF) operations in a dynamic world.

Chapter II is a review of cellular telephony. Chapter III explores the transmission of data packets over wireless local area networks (LANs). Chapter IV discusses the major trends in the development of new personal communications services. Chapter V meshes the previously described technologies with recent naval expeditionary warfighting initiatives. Chapter VI provides a summary and some recommendations for future effort.

II. CELLULAR TELEPHONY

A. INTRODUCTION

The purpose of this chapter is to familiarize the reader with the operation, architecture, and use of cellular telephony. In the remainder of this section, a brief description of the history of this technology is presented. Following this, the basic cellular architecture is introduced including concepts of frequency reuse, cell handoff, and cell splitting. A typical Frequency Modulation (FM) analog telephone call over American Mobile Phone System (AMPS) cellular is described for illustration. A brief description of modern digital cellular networks, like Global System for Mobile communications, (GSM) follows. Finally, inherent advantages and disadvantages of cellular telephones are discussed in the context of military use.

1. History: Improved Mobile Telephone Service, Statistics, Projections, Carriers

a. Improved Mobile Telephone Service

The direct predecessor to cellular telephony in the United States was called Improved Mobile Telephone Service, or IMTS. It was used during the late 1960's and 1970's. The United States was divided into market areas by the Federal Communications Commission (FCC). Only two providers were allowed in any particular market area. One

was the local exchange carrier, the other was the radio common carrier. The local exchange carrier was usually the normal local telephone service provider. The radio common carrier was often a new company attempting to compete with the local provider. Each provider would set up a base station that could send and receive radio signals to mobile users in a 20 mile radius. In some cases, IMTS allowed a mobile user to communicate by voice through the normal wired telephone network [Ref. 4]. Each radio channel could only be used by one subscriber at a time. This, combined with the low number of radio channels available, gave the IMTS a low subscriber capacity (a measure of how many different mobile users may access the system simultaneously). This is the main difference between IMTS and the modern cellular systems, which can use each frequency several times in a given geographic area. Instead of one high powered base station transmitting to a given area, cellular systems have a number of smaller, lower power stations dispersed throughout the service area, allowing the same frequencies to be utilized at the same time in several different places.

The radio and computer processing technologies needed for cellular implementation were available in the 1960's, but a working system was not deployed until October, 1983. Electrical and communications engineers at Bell Laboratories were responsible for the first cellular service. Named AMPS, for Advanced Mobile Phone Service, it was the biggest step toward true unwired telephone service. [Ref. 5]

b. Statistics and Projections

Cellular telephone subscribers are signing up for service at a rate of 32,000 per day in the U.S. At the close of 1995, 32 million subscribers were signed up, demonstrating the strong growth in the sheer number of people who desire voice service while away from their places of residence or work. The Cellular Telephone Industry Association projects that by 2000, there will be more than 60 million subscribers [Ref. 1].

People are using their cellular phones more, too. Revenues for service climbed for the twenty-second sixth-month time period in a row in 1995. People also used their cellular phones more outside their provider's service area. This "roaming" incurs higher rates, but increasing roaming revenues indicate people will pay to communicate when they need to.

The cost of cellular telephone usage has decreased steadily since 1988. Cellular Telephone Industry Association figures show the average cellular monthly bill to be near \$95.00 that year. Now, the average subscriber pays \$52.45. One of the main reasons for the drop in cost for the user is the intense competition in the domestic cellular market. Providers are literally giving phones away to subscribers who sign up for a designated time contract.

Another interesting statistic about cellular base station construction reveals the growth rate of the underlying cellular infrastructure. The number of cell sites increased by more than five thousand in the period from June 1994 to June 1995 [Ref. 1]. Cell sites are the base station antenna and radio suites that facilitate mobile communications.

c. Major US Carriers and Cellular Markets

The famous map-making company, Rand-McNally, examined the potential economic trading areas of 305 of the country's largest cities. They named these areas Metropolitan Service Areas (MSAs). Additionally, they defined 428 Rural Service Areas (RSAs). Two licenses are issued by the FCC to provider companies for each of these RSAs and MSAs. By law, one must be a local exchange carrier and the other a wireless service provider. There is a legal requirement for a provider to ensure 75% cellular coverage within each MSA. This coverage area is called the GCSA, or Geographic Cellular Service Area. Interestingly, there are no coverage requirements for RSAs.

2. System Goals

There are a number of basic operational features desired by cellular providers. When the American Mobile Phone Service was installed, the ability to handle many subscribers at once was a goal. The main reason for this was the expense of installing base stations. One base station had to be able to handle many users for the service to be cost effective. There are many ways to tackle this multiple access problem, and one will be examined later in detail. Other goals for cellular included efficient use of the available electromagnetic spectrum, nationwide compatibility, adaptability to high levels of traffic density, access to the public switched telephone network, quality of service equal to the public telephone network, and affordability [Ref.4]. Some of these original goals have been achieved better than others.

B. CELLULAR ARCHITECTURE

A cellular telephone is a radio. It sends and receives electromagnetic waves, allowing the user to communicate to distant stations while in the "coverage area" of a base station. This overview of cellular will concentrate on the AMPS model.

1. Cellular Concepts

a. Cells/Frequency Reuse

Before cellular, mobile radios could communicate with one another because they fell under the coverage of a large, high powered radio base station. As long as a user was within the line of sight of the base station antenna, they could communicate. But the number of channels available to all users within the large area was fixed. The total allocated frequency for the base station was divided into smaller frequency bands, called channels. Once the number of users desiring service equalled the number of channels, the next request for service was blocked. Other users desiring service had to wait for a channel to open.

Cellular communications handle the problem of area coverage differently. Instead of one large high-powered station, many smaller, lower powered stations are constructed throughout the area. Each "base station" covers an area called a cell, and many cells cover the same area that once was served by a single station. This reduction in size and increase in number of cells, combined with lower powered transmitters, allows the same frequencies to be used in different cells. Each frequency can be used by multiple

callers within a given service area. This method of allowing more users access to the system is called "frequency reuse."

b. Cellular Handoff

Users of the older mobile telephone services could move and communicate as long as they were within the coverage of the base station. Cellular telephone users can also move and communicate while in the coverage of a cellular base station, but they can move seamlessly from cell to cell. In order for cellular users to move seamlessly between the cells in a particular coverage area without interruptions in service, a transfer mechanism from cell to cell must be in place. This mechanism, called cell handoff, involves a very rapid switch from full-duplex communications with one cell's base station to full-duplex communications with an adjacent cell. This usually involves a comparison of signal strengths from the mobile user to all available cellular base stations to determine which cell is better able to provide the channel. This comparison and assignment is done automatically by processors in the underlying cellular network.

c. Cell Splitting

As the number of people desiring service in a particular cell coverage area increases, there may come a point when the available number of channels no longer allows the desired level of service. At this time (when demand approaches the channel capacity of a given cell), the cell can be divided into smaller segments by the insertion of new, smaller base stations. This division is known as cell splitting.

2. MSC and MTSO

When people think about cellular phones, they rarely consider the immense infrastructure that supports the cellular user. First, there are the cellular base stations. These stationary structures cost approximately .5 million to 1 million dollars to build. They contain the radio equipment that transmits signals to and receives signals from the person on the go. The cell stations are inter-connected by various means, including point-to point microwave and T-1 (1.544Mbps) land lines. There is also eventual physical tie-in between cellular base stations and the mobile telephone switching office (MTSO). This office controls the cellular network, assigns calls to cells, tracks billing, and is usually a computerized digital switch. The MTSO is sometimes co-located with the local exchange providers' central office. The mobile switching center (MSC) is the digital switch through which a cellular network physically intermeshes with the wired public switched telephone network (PSTN).

3. Subscriber Equipment

There are two main classifications of cellular phones. Some users desire service only while traveling in their vehicles. These people usually employ "mobile units," powered by the vehicle battery. These phones transmit at about 3 watts of power over an efficient antenna externally mounted on the surface of the vehicle.

Other cellular users want the ability to carry their telephone with them wherever they go. They carry "portable" units. These transmit at lesser power (approx. .6 watts).

The battery for a portable cellular telephone is internal, and the tiny antennas they use are not as efficient as the ones mobile units use.

4. Typical Cellular Phone Call (AMPS)

Each cellular telephone has a NAM, or Numeric Assignment Module. Inside this module is an integrated circuit containing the following information:

1. The telephone's assigned electronic service number (telephone number)
2. The serial number of the telephone as assigned permanently by the manufacturer.
3. Personal, user-designed access codes for physical security.

To initiate a call, the user dials the number he desires and presses "send." The MTSO verifies the calling telephone's number as valid, then gives the caller's telephone electronic instructions about what radio channel to use for communications. The MTSO then sends a signal through the PSTN to the called party's telephone, causing a ring. When the called party answers, the MTSO connects the trunk lines for each party and billing begins. When either party hangs up, the MTSO frees that radio channel and terminates billing.

C. DIGITAL CELLULAR

In the 1980's, as the popularity of cellular telephony grew in the business world, various FM analog cellular networks began to run into some practical limitations. As more and more people began to use their phones in larger cities, the area that could be covered by one cell became smaller. As a result, finding locations for cell sites became a real challenge for providers, who faced valid environmental concerns and "not in my backyard" attitudes. Another problem for cellular providers was network complexity. As the cells became smaller, "handoffs" became more numerous, making greater processing demands on the network switching equipment. Also, batteries for the telephone devices themselves were not efficient or long-lasting. Interference problems from man-made devices or other user-channels caused frequent "drops" in service. Lastly, the construction of incompatible FM analog cellular networks in Europe further reduced their utility and practicality. Traveler's could not take their FM analog phones that worked in Scandinavia and make calls with them from England. For these reasons, the development of some "second generation" cellular networks occurred in the late 1980's and early 1990's. The most distinguishing feature of these networks was that they were all digital. Tables (1) and (2) provide an overview of first generation FM analog cellular networks and second generation digital networks, respectively.

1. Global system for Mobile Communications, Industry Standard-54, and Industry Standard-95 Digital Cellular

In this section, three important digital cellular standards are highlighted. Global System for Mobile Communication (GSM) is widely used in Europe. Industry Standard-54 is a North American digital standard developed to increase the number of people who could use cellular service. Industry Standard-95 is a proprietary standard undergoing testing and limited deployment in the United States.

Global System for Mobile Communications (GSM) is a completely digital cellular network in operation today in Europe. Both the signaling information and the voice information for every call is digital. GSM was developed to provide the public with a cellular service that extended across national boundaries.

Some GSM design goals were :

- 1) Provide good speech quality
- 2) Possess low terminal and service cost per user
- 3) Support new services as they became implemented
- 4) Spectral efficiency

IS-54 is a digital cellular standard that increases the number of users who can "fit" in a particular cell by employing Time Division Multiple Access (TDMA) methods of sharing bandwidth. TDMA apportions frequency to users by assigning time slots for

signal transmission and reception. Over the analog AMPS system, most users could travel in Canada, America, and Mexico without incompatibility problems. For this reason, there was not as strong a need for a move to a digital, compatible cellular network in North America as there was in Europe. Now, "dual mode" phones are offered by cellular providers. If the user is in an area covered by an AMPS base station, the call is set up with traditional FM analog modulation. If the user is in an area with the new IS-54 capability, then his call will be time-sliced with other users. The true advantage here is that for every 30 khz AMPS channel, three users with IS-54 can communicate.

A third and final digital standard that has emerged is IS-95, a proprietary technology by Qualcomm. This Code Division Multiple Access (CDMA) technique is a Direct Sequence Spread Spectrum (DSSS) method. Spread spectrum, a wideband method that uses more bandwidth for signal transmission than what is actually needed to send given information, is a proven technology that emerged from the unique problems of the military. In DSSS, a narrowband signal is spread by a wide bandwidth pseudo-random noise (PN) code. A different code is assigned to each signal, and at the receiving end the signals are extracted out of the background noise by a special receiver that cross-correlates the received signal with a copy of the original PN sequence [Ref. 5]. Dr. Isaac Jacobs, founder of Qualcomm and inventor of CDMA, saw that spread spectrum also offered advantages when applied to cellular. Some of those advantages include greater spectral efficiency, greater system capacity, less susceptibility to co-channel interference, and better security. This standard has been tested and commercially

implemented on a small scale. Many feel it is a natural progression for cellular architectures to take, but its widespread use remains to be seen.

2. Mobile Cellular Base Stations

In the last few years, several companies (e.g., Motorola, Nokia, Ericson) have designed and manufactured portable cellular base stations. A portable cellular base station has all the functionality of a fixed base station. In addition, it provides the user with other advantages: rapid movement and installation. A portable cellular base station was used by Marines during Operation Restore Hope in Somalia. It allowed a limited number of users a reliable and portable alternative to single-channel radio nets. The base cellular station interfaced with Marine tactical switches, thus offering mobile users service outside the theatre of operations over satellite links. [Ref. 22]

Mobile cellular base stations have also been deployed with great success in disaster relief operations, both domestically and abroad. When the existing infrastructure has suffered great damage due to flood, fires, or high winds, cellular base stations can be used to allow relief agencies, law enforcement, and insurance representatives to communicate using voice and data.

Mobile cellular base stations are useful tools in the right situations. They can provide limited geographic coverage to a small number of users who need critical voice communications right away. However, they do require a power source, and they are not small enough for one man to set up or carry alone.

3. Main Advantages: Mobility, Low Cost, Data

The main advantage offered by cellular telephony to the user is personal mobility. By carrying a small, low powered cellular telephone, a user retains all the services available through the normal wired network, and gains mobility.

Cellular phones are dropping in price as more and more of them are assembled. Most providers give phones away to users who promise to sign a twelve month contract. As competition between the long distance carriers and the local providers for telephone service continues, cellular providers will no doubt join in to try and sway users to go wireless.

Cellular phones, linked to PC card modems, allow the transfer of data at rates up to 19.2 kbps. Although the cellular networks were optimized for voice traffic, they can certainly handle slow data transfer.

4. Limitations of Operational use of Cellular Telephones

One of the most obvious limitations of cellular is the need for an "infrastructure" of base stations, MTSOs, and MSCs. These facilities allow the mobile user a way back into the wired network. During a contingency, military operators may be faced with an area of operations that does not have an infrastructure, or an infrastructure that is not designed with the same standards as the continental United States. During these times, portable cellular base stations may be useful tools for rapid deployment forces to bring

into an area of operation. But, they will still require connectivity to the wired infrastructure to allow communications "out of theater."

Another problem with military use of cellular is the priority issue. All users of cellular in a particular area are "equal" in the eyes of the network. A method of assigning priority to particular users, like commanders or reconnaissance units, must be developed before military acceptance of cellular can grow. The most recent digital systems have software mechanisms that can partially address priority issues.

Yet another shortcoming of current cellular systems is the relative ease with which they can be monitored. Simple commercially available scanners can listen to cellular conversations. There are certain phones and services which help encrypt the information being sent over the voice channel, but there is information contained in the signalling data about who and where the user is that remains unprotected.

System Parameters	AMPS (North America)	TACS (UK)	NMT (Scandinavia)	C450 (West Germany)	NTT (Japan)
Transmit Frequency (MHz)					
-Base Station	870-890	935-960	463-467.5	461.3-465.7	870-885
-Mobile Station	825-845	890-915	453-457.5	451.3-455.7	925-940
Spacing (MHz)	45	45	10	10	55
Channel Spacing (kHz)	30	25	25	20	25
Number of Channels	666/832	1,000	180	222	600
Coverage of One Base Station in (Km)	2-25	2-20	1.8-40.0	5-30	5-10
Audio Signal Modulation	FM	FM	FM	FM	FM
Control Signals Modulation	FSK	FSK	FSK	FSK	FSK
Data Transmit Rate (Kbps)	10	8	1.2	5.28	0.3
Error Control	Principle of Majority Decision used	Principle of Majority Decision used	Receiving Steps Pre-determined based on content of message	Message Resent when error is detected	Transmitted signal check when sent back to the sender by receiver.

Table 1. 1st Generation Cellular Systems. After Ref. [5].

System	IS-54	GSM	IS-95	CT-2	CT-3/DCT-900	DECT
Country	US	Europe	US	Europe, Asia	Sweden	Europe
Access Technology	TDMA/FDMA	TDMA/FDMA	CDMA (DS)/FDMA	FDMA	TDMA/FDMA	TDMA/FDMA
Primary use	Cellular	Cellular	Cellular	Cordless	Cordless	Cordless/Cellular
Frequency Band -Base Station (MHz)	869-894	935-960	869-894	864-868	862-866	1800-1900
-Mobile Station (MHz)	824-849	890-915	824-849			
Duplexing	FDD	FDD	FDD	TDD	TDD	TDD
RF Channel Spacing (kHz)	30	200	1,250	100	1,000	1,728
Modulation	DQPSK	GMSK	BPSK/QPSK	GFSK	GFSK	GFSK
Power, Maximum/Average (mW)	600/200	1000/125	600	10/5	80/5	250/10
Frequency Assignment	Fixed	Dynamic		Dynamic	Dynamic	Dynamic
Power Control -Base Station	Y	Y	Y	N	N	N
-Mobile Station	Y	Y	Y	N	N	N
Speech Coding	VSELP	RPE-LTP	QCELP	ADPCM	ADPCM	ADPCM
Speech Rate (kbps)	7.95	13	8	32	32	32
Speech Channel per RF Channel	3	8		1	8	12
Channel Bit Rate	48.6	270.833		72	640	1,152
Channel Coding	1/2 Rate Convolutional	1/2 Rate Convolutional	1/2 forward, 1/3 rate reverse, CRC	None	CRC	CRC
Frame Duration (ms)	40	4.615	20	2	16	10

Table 2. 2nd Generation Cellular Systems. After Ref. [5].

III. DATA OVER WIRELESS

A. INTRODUCTION

A wireless local area network (LAN) gives computer users mobility in limited geographical areas, such as campus or office building environments. By using mobile computing devices, people can move about freely and still remain connected to the wired LAN. Wireless LANs are growing in popularity due to their steadily improving performance, decreasing prices, and emerging standards. Revenues from the sale of wireless LAN products exceeded \$157 million dollars in 1995, and are expected to reach \$725 million dollars by the close of 1998 [Ref. 6]. The main advantage of wireless LANs is untethered mobility. Other important benefits include reduction of associated infrastructure costs, like wiring, installation, and maintenance. It is also easier to reconfigure wireless LANs than wired LANs. Wireless LANs have found their first business niche in vertical markets like warehouse inventory control, manufacturing plant maintenance, retail stores, and hospitals. In each of these markets, a worker carries a mobile computer or pen-based personal digital assistant (PDA). These devices have radio frequency (RF) wireless links with access points to the wired LAN which are located at intervals throughout the work environment. An access point of a wireless LAN is simply a physical site that joins the wired LAN to the wireless component of the LAN.

1. Two Generic Types of Wireless LANs

There are two generic applications of the wireless LAN. The first, called the infrastructure wireless LAN, is the model described above in the vertical market arena. A user possessing a small computing device is wirelessly provided access to computers and servers to conduct queries, file transfers, and other applications. These services are enabled by the presence of access points in the work environment. The other type of wireless LAN is the ad hoc wireless LAN. An example of an ad hoc wireless LAN is two mobile computer users swapping files via infrared ports on their computers. There is no cable or disk transfer. Rather, the information is passed over the air. [Ref. 7]

In this chapter, we examine how the problem of moving packets of data over the airwaves was originally solved by scientists in Hawaii. Then, large-scale wide-area data networks, ARDIS, RAM Mobile data, and CDPD are described. Finally, the very latest small scale wireless LAN products available today are reviewed.

B. PACKET RADIO CONCEPTS

Packet radio systems allow the operation of a data network over a wide area using wireless, not wired, connections. A packet is a logical grouping of information, usually consisting of user data and control information. The user data is the useful material, like a word processing file, that people want to share. The control information includes source and destination addressing, sequencing information, flow control, and error correction data.

1. ALOHA

According to Garg and Wilkes [Ref. 5] reasons for using wireless data networks may be economic, physical, or a combination of both. It may be cost-prohibitive to install all the cable needed for an organization's needs. Likewise, there may be an implied need for mobility in the data transfer application.

In the 1970's, the University of Hawaii was faced with a data transport challenge. Various remote data stations spread throughout the islands needed to be connected to the main data center. It was infeasible to run cable or wire from the remote sites, so the engineers set up a packet radio network. In setting up this network, they encountered a data collision problem. Data from two or more remote sites could not be received simultaneously. If simultaneous transmission occurred, some data would be lost at the main center. Wired LANs can avoid data collisions by sensing every other devices' activity on the network. That is, on wired networks, each terminal knows when another is going to send data, so it does not send until it is "quiet" on the network. Wireless sites do not have this luxury. They must send data independent of what other stations might be doing at that instant. In Hawaii, some stations were hidden from others by hills or man-made obstructions. These stations could not know what activity transpired at other sites. For this reason, more robust protocols needed to be incorporated into the design of the wireless system. Protocols are formal sets of rules by which computers can communicate, including session initiation, transmission maintenance, and termination. The lessons learned in the implementation and use of this network, called ALOHA,

helped engineers begin the process of developing newer, more powerful protocols to send data packets over the air efficiently, at lower cost, and with acceptable error rates. [Ref. 5]

2. Protocols for Wireless Data Communications

Currently, two main wireless LAN standards are under development. In the United States, the IEEE has titled its wireless data standard IEEE 802.11. This standard is not complete, but its foundations were agreed upon in November, 1993. IEEE 802.11 defines a common Media Access Control (MAC) protocol for all wireless LAN products. This standard is multifaceted. It incorporates the following range of physical layer options:

1. 1 and 2 Mbps using Frequency Hopping Spread Spectrum radio
2. 1 and 2 Mbps using Direct Sequence Spread Spectrum radio
3. 1 and 2 Mbps using direct modulated infrared
4. 4 Mbps using carrier modulated infrared
5. 10 Mbps using multi-subcarrier modulated infrared.

The IEEE 802.11 standard is good for users of wireless LAN products, because as vendors move away from proprietary standards to 802.11, the cost of building integrated circuits will fall. Wireless LAN devices will follow this trend and become more cost effective, as well.

The other standard is a Pan-European effort by the European Telecommunication Standards Institute (ETSI) and is called HiperLAN. It calls for a user bit rate of 10-20 Mbps and a radio carrier, not infrared. [Ref. 7]

C. ADVANCED RADIO DATA INFORMATION SERVICE (ARDIS)

A joint venture by IBM and Motorola, the ARDIS packet radio network is a wireless wide area data network. Wide area networks cover geographic areas the size of cities and metropolitan areas. Subscribers of the ARDIS network can transmit and receive data through specialized mobile terminals. ARDIS was implemented in 1990 to assist IBM workers in the field. The mobile data transfer capability became so useful and simple that Motorola and IBM offered the service to the public.

1. Brief Description

ARDIS is a two-way data network. The architecture of ARDIS is not cellular. Hand offs are not a part of network design. Instead, in metropolitan areas, a single frequency pair and multiple base stations are used. User terminals often transmit to more than one base station. The network monitors signals received from user terminals and determines the one with the lowest error rate. One 25 kHz channel is used to transmit from base stations, and another 25kHz channel is for received signals [see Figure 1]. A proprietary packet radio modem is required for users to connect to ARDIS. This modem attaches to the serial port on the user's laptop PC or PDA and allows data transfer. Users can be located within office buildings or moving on highways. The ARDIS network uses

frequencies in the Specialized Mobile Radio (SMR) 800-Mhz band to allow excellent coverage in buildings and on city streets. Besides good coverage, users are only billed for the amount of packets actually transferred, not for the duration of the modem link. There are 1350 ARDIS base stations nation-wide, and service is available in over 10,000 US cities. 40,000 subscribers currently use ARDIS, which can provide reliable data transfer at up to 19.2 kbps.

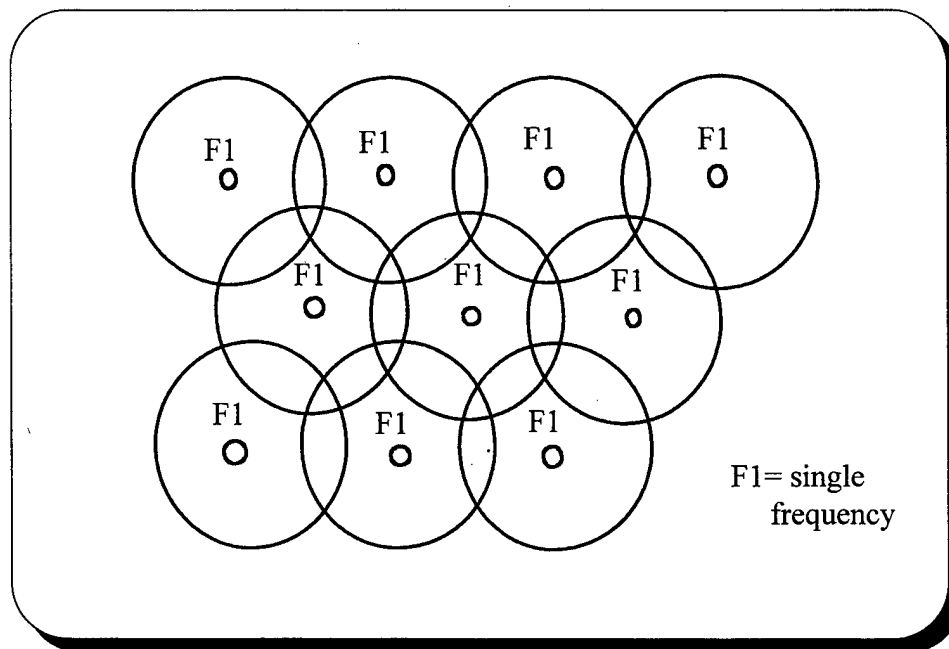


Figure 1. ARDIS Single Frequency Area Coverage. After [Ref. 5].

D. RAM MOBILE DATA (ERICSSON SPECIALIZED MOBILE RADIO)

The RAM Mobile Data Network is a wide area wireless data network. RAM was a joint creation of Bell South and RAM Broadcasting to provide packet data service throughout the United Kingdom and the United States. The Mobitex protocol, used by the

network and developed by Ericsson Inc., is a proprietary standard based on the seven layer open systems interconnection (OSI) reference model.

1. Brief Description

Subscribers of the RAM Mobile Data service use a special radio modem to access the network. Uses vary, but primary functions include wireless dispatch services, messaging, remote data collection, remote database access, access to credit card validation, and automatic vehicle location. Unlike ARDIS, RAM uses several channels and frequencies in the 896-901 Mhz range. Frequency reuse is incorporated in the network design. RAM states that their network has a radio channel capacity of 2,800 to 13,000 packets per hour, depending on the average message length. Additional radio link capacity can be added by increasing the number of base stations.

The main parts of the RAM network are the mobile radio modem, the base station, the local switch, the regional switch, and the network control center. The radio modem is a small 2 to 4 watt device, about the size of a brick, with a small half wave dipole antenna. The modem connects to the subscriber's laptop PC or personal digital assistant via an RS-232 interface. When activated by software in the PC, the modem "searches" certain frequencies for the electronic signature of a local base station. The base station provides the radio interface to the radio modems in the field. It also provides traffic routing within its local area, support for terminal "roaming" in the local area, and security. If the rest of the network crashes or links with other base stations are lost, each

base station can still provide service for users in its coverage area. The local switch handles control and data transfer between base stations in an area. The regional switch handles the same information, but for larger geographic regions (long distance). Finally, the network control center supervises the entire RAM system. It allows network managers to perform network operations and maintenance, provisioning of subscribers, alarm handling and statistics, and traffic calculations. The network control center does not participate in traffic routing. This function is performed at the base station and local switch level.

E. CELLULAR DIGITAL PACKET DATA (CDPD)

CDPD is another wireless wide area data network working in the US today. Like ARDIS and RAM, it is a packet switched, not a circuit switched network. This means that instead of setting up unique physical circuits for each data transfer (like a normal phone call) packets of information travel over many different routes, ending up in the right place in the right order. CDPD does not operate on a special, proprietary network. Instead, it uses the existing AMPS cellular network to move data. Designed as a transparent overlay to the AMPS system, CDPD waits for pauses in the voice transmissions on the network. When these pauses occur, CDPD fills the gap with data packets, thus increasing spectral efficiency in the allocated bandwidth.

CDPD is a connectionless, multiprotocol network service that provides a "peer network extension" to an existing data communications network. "Connectionless" means

there is no prior physical or virtual circuit establishment between the sender and the receiver. CDPD routes packets from one mobile user to the network independent of the path. CDPD supports two connectionless network protocols, the internet protocol (IP) and the Connectionless Network Protocol (CLNP). These protocols facilitate data communication, regardless of the network hardware being accessed by the mobile user.

Mobile users need to possess a CDPD capable modem, an AMPS standard cellular phone, and a computer to conduct data communications. The link between a mobile CDPD user and the cellular base station is a shared resource, where multiple mobile devices share and contend for use of the radio channel. When discussing cellular channels, "forward" refers to transmissions from the base station out to the mobile subscriber, and "reverse" refers to the transmissions from the mobile subscriber back to the base station. In a single cell, all CDPD devices operate on the same reverse channel. CDPD uses a mechanism called Digital Sense Multiple Access (DSMA) to solve the problem of multiple devices contending for the same resource. In DSMA, mobile devices are sent "busy/idle" information from the base station. This information tells a device that wants to send data whether the channel is already occupied by another device. If the channel is clear, the device sends a data burst. If the channel is occupied, the device waits a random amount of time, then tries again. Another aspect of DSMA is determining whether a piece of information got from the mobile user to the base station. This is accomplished by a "decode status" indicator. This mechanism ensures reliable

transmission by letting the sending device know that its data was properly decoded by the base station.

CDPD uses one other useful technology for reliable data transfer called Reed-Solomon forward error correction (FEC). Forward error correction mechanisms can reduce the number of bits that are corrupted by the dynamic and noisy radio environment. FEC mechanisms pre-encode the data message with special error correction bits. Then, if some bits are corrupted, the receiver can execute a decoding algorithm that allows recovery of the original data, without the need for retransmission. Reed Solomon FEC uses a format of (63, 47) coding. This means the data is transmitted as 63 symbols of 6 bit length. 47 of these symbols carry user data, while the remaining 16 carry error correction and detection information. Using this coding scheme, it is possible to correct up to 48 corrupted bits in each 378 transmitted. Reed-Solomon code provides an undetected error probability performance of better than 2.75×10^{-8} [Ref. 11]. This probability performance means that the case of a corrupted bit being both undetected and uncorrected is extremely rare.

F. WIRELESS LOCAL AREA NETWORKS

At this point, smaller scale wireless LANs will be the focus. These LANs do not attempt to provide nationwide, city-wide, or even global coverage. Rather, they are designed to operate in campus, warehouse, or office building environments. These environments support numerous verticle market applications, as discussed at the

beginning of this chapter. These LANs are not intended to replace wired LANs. Rather, they are used to create convenient wireless extensions back to the wired LAN for users.

1. Parts of the Wireless LAN

The smaller scale wireless LAN works in a manner analogous to the larger scale networks. A "wireless client adapter" (usually taking the form of a PC card) plugs into a pen-based digital assistant or palmtop computer. This adapter sends spread spectrum radio frequency energy out to "access points" that are scattered to provide optimum coverage in the work environment. Each of these access points is physically tied to the wired LAN.

2. Three Kinds of Wireless LANs

Wireless LANs currently come configured in one of three different technologies for radio frequency data transfer. They are, frequency hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), and infrared. The spread spectrum methods use frequencies located in the Industrial, Medical, and Scientific (ISM) bands of the electromagnetic spectrum. These frequencies are at the 902 to 928 Mhz and 2.4 to 2.484 GHz ranges. The FHSS LANs use a technique by which the transmitted signal "hops" among several frequencies at a specific rate and sequence as a way of avoiding interference. DSSS LANs employ a technique called "chipping." Data is divided into small units, called "chips." Special radio transmitters employ a mathematical function to spread chips over a fixed range of the frequency band. Although they use more power and

are more expensive to manufacture than FHSS, DSSS LANs have higher raw data throughput. The infrared LANs have two common forms. They are "line of sight," which focuses the light beam on a narrow path, and "diffuse," which transmits light in a spherical pattern [Ref. 6]. One familiar application of a line of sight infrared signal is the remote control device for many television sets.

3. Common Features of Wireless LANs

All commercially available wireless LANs share these common characteristics:

1.) Roaming is the greatest visible advantage of installing a wireless LAN. Wireless LAN users can roam their environment without dropping the connection with the wired LAN. If the user moves away from an access point, the wireless client is actively seeking a stronger signal from others. The hand-offs from access point to access point take place transparent to the user.

2.) Performance of wireless LANs is markedly slower than that of wired LANs. As of early 1996, the best products will still only achieve reliable rates of 1.5 Mbps. Although this is slow compared to Ethernet or fast Ethernet, users can still do useful things like check E-mail and save small documents wirelessly.

3.) The radio technology used by the latest wireless LAN products is spread spectrum. FHSS or DSSS are the options. Each technique has advantages and limitations. FHSS systems have slower throughput, but they are less susceptible to interference and use less battery power at the client device. DSSS systems provide better throughput

performance, but fail to take advantage of multiple access points when numerous people are accessing the network.

4.) Finally, all wireless LANs must be installed, operated, and maintained by people. Most systems come with management software and test equipment to help installers choose the best number and location of access points, and some have better training materials and support to get users comfortable with the LAN quickly.

4. An Example of a Popular Wireless LAN Product

Proxim Corporation's RangeLAN2 was PC Magazine's selection as best of the wireless LAN products available today [Ref. 6]. It is a FHSS system with excellent performance. It comes with a software utility that allows easy configuration of access points from a central network location. The product comes complete with site survey tools, allowing efficient setup and layout of LANs. Roaming with the RangeLAN is seamless. The system can handle up to 15 separate access points in a given work area. These numerous access points can simultaneously handle several users in the area. The network uses non overlapping frequencies to optimize signal strength and minimize errors.

In this chapter, wide area and local wireless data networks have been overviewed. Moving information over the air provides a new flexibility in the design and cost of LANs. Although wireless LANs will unlikely match the rates and reliability of wired

systems, their convenience and low costs offer much to mobile workers in many industries.

IV. PERSONAL COMMUNICATIONS SERVICES

A. WHAT ARE PERSONAL COMMUNICATIONS SERVICES? (PCS)

PCS are a variety of new wireless telecommunications technologies, networks, products and frequencies. PCS has many different definitions, based on different perceptions of the current and future digital wireless world. In the media, PCS has been called "the future of wireless telecommunications." Systems engineers describe PCS as "the anticipated future integration of wireless communications capabilities into a single service or set of services." A broad definition of PCS is "a general category of current and future wired and wireless technologies providing a wide array of services to users any place and any time." This definition would include the following: digital cellular telephony, paging systems, wireless networks, packet radio, cordless telephones, personal digital assistants, notebook PC's, specialized mobile radio, and even mobile satellite services. [Ref. 12]

The most widely used meaning of PCS, however, and the one that best supports this study, is a "specific concept for a future integrated system that will equip mobile users with low-power (less than one watt of transmit power) handheld terminals providing access to a full range of services including voice communications, interactive paging, facsimile, data, and imaging." [Ref. 12]

Three aspects are key to understanding this concept:

- 1) User can be located anywhere on earth.
- 2) User carries a small integrated device that assists in accessing the desired service.
- 3) The user's device is "aware" of its place in the global network, and can provide access via a wireless link to the wired infrastructure, where the "services" exist. This link may be terrestrial, or it could involve a low, medium, or geostationary orbit satellite.

1. US Federal Communications Commission PCS Block Auctions

In the United States, a great deal of activity has taken place in recent years to pave the way for PCS implementation. Much of this activity has involved the organization of frequency bandwidth for the new services. The FCC has set aside the frequency range of 1.8 to 2.2 GHz for PCS in the United States. This bandwidth, divided into six blocks labeled A through F, is the wireless "real estate" of the information age. See Table 3. The FCC has organized a "competitive bidding" (auctioning) process to promote competition for these valuable slots of frequency. The winner of each block auction is free to use any desired air interface and system architecture, as long as it complies with rules governing transmit power levels [Ref. 13]. Blocks A and B are already claimed. Sprint Telecommunications Venture, an alliance of Sprint Corp. and three cable companies, won most of these blocks in March 1995 auctions [Ref. 14]. Blocks C, D, E, and F are slated

for auction in 1996. Block C auctioning has been delayed for various legal reasons. Block C was designated the area where small entrepreneurs, women, and minorities could bid for precious space on the airwaves. Once a company or service provider secures a portion of frequency, they can apply for a license from the FCC to provide services and products to consumers in 492 Basic Trading Areas (BTAs) or 51 Major Trading Areas. (MTAs) These trading areas are similar to cellular service apportionment.

Channel	Block	Frequency	Service Area
A	30 MHz	1850-1865/ 1930-1945	MTA
B	30 MHz	1879-1885/ 1950-1965	MTA
C	30 MHz	1895-1910/ 1975-1990	BTA
D	10 MHz	1865-1870/ 1945-1950	BTA
E	10 MHz	1885-1890/ 1965-1970	BTA
F	10 MHz	1890-1895/ 1970-1975	BTA

Table 3. US PCS Spectral Allocations. After Ref. [4.]

a. First Commercial PCS Service in US

The first licensee to get a PCS network built and working in the United States is American Personal Communications. This company launched its system in the Washington, D. C. metropolitan area in November, 1995 [Ref. 14]. American Personal Communications is a partner in the Sprint Telecommunications Venture, the first big

winner of the initial block auctions. Although the Washington, D.C. coverage is a good start, the rest of the Sprint PCS infrastructure, planned to span much of the East Coast, is unbuilt.

B. PCS FREQUENCY AND STANDARDS ISSUES

The question many ask about PCS is whether these new systems will be designed to certain standards and be interoperable worldwide. Joint Publication 6-0, Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations, contains the following definition: Interoperability, "the condition achieved among communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users."

Although there are some indications of PCS providers are attempting to cooperate and move to some core standards, a global look at current PCS implementation reveals many competing and non-interoperable networks. The opportunities for major profits have spurred providers to get products to market early. This rush has caused a number of different and non-interoperable PCS networks to emerge.

Since 1992, Canada has struggled to get a PCS network into place. But the frequency range they chose first was in the 900 MHz range. When the US opted for the 1.8 to 2.2 GHz range, the Canadian government realized it would have to begin licensing PCS suppliers for the same frequencies in order to ensure cross-border PCS connectivity in North America. [Ref. 14]

The U.K. has seen the most successful implementation of a PCS network thus far. In 1993, Mercury One-to-One in London became Europe's first commercial PCS network. Additionally, Orange, a network set up by Hutchison Telecom, has also been successfully built. Both of these networks have become popular with users in England. Both companies compete directly with cellular providers there. Representatives from future hopeful U.S. PCS providers have visited the U.K. to learn about successful PCS implementation and marketing. [Ref. 14]

Across Europe, many countries are implementing a PCS standard called DCS-1800. This digital network possesses many of the same technological standards as Global System for Mobile Communications (see Chapter II). GSM is a digital cellular network, and DCS-1800 is a digital PCS network. Although the two are planned to be interoperable, DCS-1800 will offer more advanced services, reliability, security, and quality than GSM. [Ref. 14]

In rapidly advancing countries like Singapore and Thailand, people are not waiting for telecommunications companies to provide wire to their homes, places of work, or public places. Instead, these nations are "leapfrogging" to the latest wireless PCS technologies. GSM is the widely deployed standard for cellular in this region, so DCS-1800 may follow as the natural PCS standard. [Ref. 14]

Finally, in Japan, the digital Personal Handy Phone, or PHP standard, has emerged as a popular PCS standard.

The various systems mentioned above have many similarities, but differences in modulation, speech coding, multiple access approach, and power usage will hinder the ability of users to roam worldwide with one handheld device for service. In the United States, a Joint Technical Committee (JTC) of the Alliance for Telecommunications Industry Solutions (ATIS) was formed in 1992 to review potential standards submitted by contributors, and make recommendations. As of early 1996, the JTC has narrowed the initial list of 16 standards offered for US implementation to 7. These are:

- 1.) Personal Access Communications Services (PACS) from Bell South.
- 2.) A GSM based standard, similar to DCS-1800.
- 3.) IS-54, a TDMA digital approach.
- 4.) IS-95, a QUALCOMM proprietary offering.
- 5.) Digital European Cordless Telecommunications (DECT).
- 6.) A hybrid TDMA/CDMA approach.
- 7.) A wideband CDMA approach.

Time, commercial viability for new PCS markets, and user demand will be the only truth tellers for PCS. It seems clear that various PCS networks are emerging in different regions at different times. Fleet Marine Forces are tasked to be prepared to operate in any

environment. Many parts of earth are not covered by these networks, and Marines do not have the funds to acquire the means to access all of them. Space-based service may provide the flexibility Marines need.

C. MOBILE SATELLITE SERVICES AND GLOBAL PCS

Numerous short term contingency operations have occurred since the fall of the Berlin Wall in November, 1989. Marines have deployed as MAGTF's or as a part of joint task forces (JTFs) to respond to humanitarian missions, disaster relief operations, and peacekeeping operations. Many of these operations have occurred in regions of the world that do not have wired telecommunications infrastructure. Often, joint US forces have had to bring a military communications infrastructure with them as they responded to mission taskings. New mobile satellite services, emerging from a number of commercial sources, may be a valuable asset for these types of operations. Mobile satellite services offer the extension of terrestrial PCS services to other networks via satellite links. These may prove to be the most valuable offering yet seen for Marines responding to varied, time-sensitive contingencies.

1. Current Proposed Global PCS systems

It is not the purpose of this study to explore the benefits of certain satellite communications architectures when considering PCS service provision. There are

tradeoffs in cost, complexity, and capability in every system involving a space component. Three different satellite altitudes, however, have emerged as distinguishing features of some new mobile satellite service proposals. The altitudes are low earth orbit (LEO), medium earth orbit (MEO), and geostationary orbit (GEO). The following paragraphs briefly describe the known characteristics of the most recent proposals for global PCS via mobile satellite service.

Iridium is a LEO-based global network of 66 satellites. The network, planned for 1998 operational service, will allow users anywhere on earth to communicate from wireless handheld telephones. As the satellites rapidly pass over users below, they would intelligently hand-off the user's transmissions via crosslinks to the closest appropriate satellite. Links from the satellites to appropriate ground stations would let the "call" enter the public voice network. Clearly, the large number of satellites implies a very complex network management problem. Also, users may be within the coverage area of a terrestrial system, thus canceling the satellite access needline. Iridium phones will be dual-mode. They will support both terrestrial and satellite connectivity, depending upon the location of the user. Low rate data transmission is another expected service. The Iridium program is six months ahead of schedule, with the first satellites planned for launch in mid 1996. [Ref. 12]

GlobalStar is another proposed LEO network by Loral Space Systems and Qualcomm Corp. This proposal places a set of four satellites in each of six 700 nautical mile coplanar 40 degree inclined orbits for a total of 24 in the constellation. The proposed

multiple access technique for user services would be Qualcomm's proprietary Code Division Multiple Access (CDMA). As proposed, the system would offer positioning, voice, facsimile, and data services using small wireless handsets. [Ref. 12]

Ellipsat, a LEO system proposed by the Ellipsat Corp., is targeted at cellular service providers. The company hopes to offer range extension services via their satellites for current terrestrial cellular networks. [Ref. 12]

OrbComm, a network proposed by Orbital Communications Corporation, would provide two levels of global service. Level one would involve simple alphanumeric data communications and position determination. Level two would provide low capacity data access and messaging for users. The multiple access method envisioned for the OrbComm network is frequency division multiple access (FDMA). In October of 1994, the first FCC license for a global PCS service was given to OrbComm.

VITASat, a small entrepreneurial venture, launched the first of two LEO satellites in 1994. The main purpose of this system will be data messaging services for developing countries.

Teledesic, a communications consortium that includes backing from Microsoft Chairman Bill Gates, has a LEO proposal calling for 840 satellites. These would operate in the Ka frequency band and provide audio, video, and data services at bit rates from 16 Kbps to 2.048 Mbps. This system would not be primarily focused on PCS services as others covered here.

Odyssey is a proposed MEO system from TRW Corp. Twelve satellites would make up the space segment of the network. The network would provide positioning, messaging, voice, facsimile, and data services to users. CDMA is the proposed multiple access technique.

INMARSAT P is a proposed satellite access service offering voice, paging, and low rate data transfer for users. Its architecture includes 12 MEO satellites of simple design and no crosslinks between satellites. Network control, including service hand-offs, will be conducted from ground stations. INMARSAT or International Maritime Satellite Consortium, is a well known group of companies providing a wide range of commercial satellite services. INMARSAT P is their PCS market solution.

Geostationary satellites with PCS functionality include MSAT, ACTS, MOBILESAT, and NSTAR. GEOS satellites are excellent for worldwide coverage, but require significant power levels from earth to receive reliable signals.

D. GLOBAL POSITIONING SYSTEMS AND PCS

The Global Positioning System (GPS) has become almost ubiquitous in the US military. The national defense authorization for Fiscal Year 1994 states that after September 30, 2000, funds may not be obligated to modify or procure any DoD aircraft, ship, armored vehicle, or indirect fire weapons system that is not equipped with a GPS receiver [Ref. 15]. GPS gives users a current location based on triangulation from signals constantly transmitted from at least four geosynchronous satellites. Accuracy to 1 meter

is available for military GPS receivers. The user receives his location in hours, minutes, and seconds of latitude and longitude, but these can be converted to map coordinates with the right software. Some of the current uses for GPS include: enroute navigation, low-level navigation, target acquisition, close air support, missile guidance, all weather air drops, sensor emplacement, precision survey, space navigation, approach and landing, remotely piloted vehicle operations, search and rescue, photo reconnaissance, ELINT annotation, range instrumentation, and inertial updates. [Ref. 15]

In addition to GPS, Global Locationing System (GLS) is becoming popular. GLS is an active system. A GLS transmitter is mounted in a vehicle, for example, and sends out signals to reception towers. These towers transfer the signal into direction data, and forward this to a central tracking facility. The tracking facility can then determine the vehicle's position, speed, and direction of travel. [Ref. 8]

1. Integrated GPS Capability

GPS and GLS are technologies that will integrate very easily with PCS. The electronics needed to conduct GPS positioning are tiny and require little power. These characteristics will allow their incorporation into future PCS handsets. Users will have the ability to determine their precise location and share that information with others, automatically if desired. Both of these functionalities will come from the same device.

E. PAGING SERVICES

Paging technology is well established, and has become inexpensive and popular in the commercial world. Paging at its most basic transmits a telephone number to a small, wearable receive unit (beeper) within a coverage area. Advanced paging services available now include the ability to send small alphanumeric text messages to the receive unit, increasing the utility of the service. Paging is an example of an asymmetrical communications network. The base station is usually a large, high powered tower that has considerable range. The receive device is a receive-only, battery-operated device. The asymmetry derives from the large amount of power and data being sent out from the tower, contrasted with the tiny, receive-only pager.

1. Skytel's 2 way Paging service

In 1995, SkyTel wireless services introduced a limited 2-way paging service in 1300 US cities [Ref. 16]. For \$24.95 a month, users get 100 local messages a month on their pagers, as well as complimentary news headline services. The messages users can send out from their tiny six ounce pagers are limited to short, canned responses. People can select a response to a page from a pre-formatted list. SkyTel expects to offer a more custom message capability in the near future [Ref. 17].

F. MILITARY CONSIDERATIONS FOR PCS

At the beginning of this chapter, PCS was offered as a very promising set of technologies and new capabilities that would significantly enhance the ability of Marine

Air Ground Task Forces to communicate worldwide. This section briefly summarizes the major reasons why PCS and military C4I are a good match.

1. Mobile Capability

For dynamic, rapidly evolving combat operations, contingency operations, military civil assistance activities, and field exercises, a wireless and mobile communications capability for voice and data is a standing requirement. PCS offers commanders at all levels in all services new and more robust ways to share information, regardless of location.

2. Low Power

PCS offers low power, handheld devices that allow connectivity with digital networks. For a soldier or Marine who must carry a great deal into combat, a small device that is lightweight and non obtrusive is a benefit. Low power also carries the implications of less probability of intercept and fewer battery requirements. A device that is battery efficient, possessing power management and "sleep" modes, lightens the load of the foot-mobile Marine.

3. Proliferation of Notebook, Palmtop PC's and PDAs at lowest levels

The continued lowering of prices for integrated circuits and display screen technology has helped notebook computers, palmtop PCs and personal digital assistants become more prevalent at lower and lower levels of the military [Ref. 12]. This has, in turn, magnified the need for better ways to allow these computing devices to talk to one another. PCS will be an enabling technology allowing lower echelons of the military to share information. PCS will probably not directly replace existing systems, such as combat net radio or ground mobile forces (GMF) satellite communications. Rather, it will offer enhancements and fill holes in existing systems.

4. Separate Categories Now Merging

This paragraph from an emerging technologies assessment describes the blending of systems taking place.

For the next generation of tactical wireless communications, many DoD planners believe the boundaries among the categories of networks will be blurred and that a highly integrated multifunctional capability will evolve, providing tactical users with messaging, image transmission, low frame-rate video, sensor traffic, database query/response, fire control, intelligence, and other functional capabilities. This integrated capability will be essential for providing C4I support to the warrior, as this multimedia, cross-border concept evolves over the next few years [Ref. 12].

V. WIRELESS APPLICATIONS FOR MAGTF'S

A. INTRODUCTION

The preceding chapters have provided a technology review of current wireless communications. This chapter will highlight areas where certain wireless devices, networks, or services could enhance command and control for Marine Air Ground Task Forces (MAGTF). First, the MAGTF is defined, and key ideas behind this organization are presented. Next, SEA DRAGON, an advanced concept for naval expeditionary warfare is discussed, with emphasis on where wireless technology insertion offers good solutions. Following this, the author briefly presents some applications that could benefit our warfighters today. Finally, a Marine cellular initiative and an ARPA research project are described to point to possible future wireless implementation.

B. MAGTF ORGANIZATION AND CONCEPT

1. Organization

The MAGTF is the building block for understanding how Marines organize to fight. The important concepts behind the setup of the MAGTF are total integration, task organization, and a single commander. Total integration means ground forces, aviation elements, and combat service support elements form a unit that trains and fights as a team. Task organization means the commander can tailor the type and quantity of forces

he needs to accomplish specific missions. Lastly, a single commander gives a common vision and focus to the entire unit, allowing unity of effort and great flexibility.

MAGTF's vary in size, but three common configurations are the Marine Expeditionary Force, the Marine Expeditionary Brigade, and the Marine Expeditionary Unit. Regardless of size, any MAGTF will include a Command Element (CE), a Ground Combat Element (GCE), an Air Combat Element (ACE), and a Combat Service Support Element (CSSE). This study concentrates on the smallest MAGTF, the Marine Expeditionary Unit.

2. Mission

Marine Expeditionary Units conduct amphibious operations in support of US and allied forces [Ref. 18]. Specific MEU missions include: amphibious raids, limited objective attacks, noncombatant evacuation operations, show of force operations, reinforcement operations, security operations, mobile training teams, civic action operations, military tactical deception operations, fire support control, counterintelligence operations, signal intelligence/electronic warfare operations, tactical recovery of aircraft, equipment, and personnel, recovery operations, specialized demolition operations, military operations in urban terrain, and in extremis hostage rescue. [Ref. 18]

The Ground Combat Element of a MEU is a reinforced infantry battalion, with three rifle companies, a headquarters company, a weapons company, and a reconnaissance platoon. The Air Combat Element of a MEU is a composite squadron of

various aircraft, including CH-53E and CH-46 helicopters, AH-1 and UH-1 helicopters, and a detachment of AV-8B Harrier aircraft. The Combat Service Support Element of a MEU is called a MEU Service Support Group (MSSG) and contains detachments of engineers, maintainers, communicators, motor transport, and supply.

C. SEA DRAGON AND WIRELESS

1. A New Concept for Naval Expeditionary Warfighting

Introduced in December, 1995 by the Commandant of the Marine Corps and the Director of the Commandant's Warfighting Laboratory, SEA DRAGON is a vision for shaping naval expeditionary warfare into the next century [Ref. 2]. It is naval in character, because Marines spend much of their forward-deployed time on ships near the world's extensive littorals. SEA DRAGON thinking acknowledges that the battlefield environment is greatly changed, even since Operations Desert Storm and Desert Shield. The precise leveraging of the right technologies is another aspect of SEA DRAGON. To quote Gen. Charles Krulak, USMC, "we must equip the man, not man the equipment." SEA DRAGON is an advanced warfighting concept. It seeks to more closely unite fleets and fleet marine forces to exploit tempo, precision, lethality, mobility, and information.

2. Areas of Focus for SEA DRAGON

There are several areas requiring development to ensure the success of SEA DRAGON. The Commandant's Warfighting Laboratory labels these areas, "long poles in the SEA DRAGON tent." They are:

1. Command and Coordination
2. Fires and Targeting
3. Maneuver and Mobility
4. Survivability
5. Sustainment
6. Training and Education

Command and coordination ties together all of the other areas, so this study will concentrate on it. As envisioned, the future naval expeditionary force comes from the sea, keeps the buildup of assets ashore to a minimum, and disperses small but highly capable teams into the area of operations. The wording, "command and coordination" vice "command and control" implies a move to a centrally coordinated but decentralized execution model. The basic requirements of communications remain important to SEA DRAGON. The new idea, however, is how these traditional requirements are manifested. "These requirements are still necessary and manifest themselves in the development of a

dynamic, extensible network which connects individuals, organizations, sensors, weapons systems, command and control systems, and information systems in a universal architecture." [Ref. 2] In the author's opinion, the only "dynamic, extensible network " that offers the flexibility and cross-echelon connectivity sought for SEA DRAGON is a wireless one. The idea of forces, platforms, weapons, commanders, and sensors sharing information on a dynamic, seamless network is the true new thinking here.

3. Command and Coordination Capabilities

In this section, some of the important required capabilities of a SEA DRAGON command and coordination system are listed. Following each listing is a pointer to a wireless device, service, or application that could enhance the capability.

1. *The capability to establish and extend a command and coordination network from sea-based command elements to forces deployed ashore, to include individual units which are widely dispersed across hundreds of miles.*

A cellular network, with its wide area coverage, user mobility, and large user capacity, may be one element of a command and coordination solution. The network could be terrestrial or space-based. For the terrestrial model, small units may use the same cellular network provided commercially in the country of concern. If there is no infrastructure, units will need portable base stations, small but powerful in design, that can provide a "bridge" to the wired voice network. Bridges back to amphibious shipping could be Unmanned Aerial Vehicles, manned aircraft, even lighter-than-air craft. Another

possibility is space-based service. Worldwide paging via satellite may provide an easy way to reach scattered teams of Marines operating many miles apart with the same information. For shipboard command elements, a worldwide PCS capability, provided commercially, may provide a powerful new way for leaders to keep each other informed and make better decisions. What PCS will offer is the ability for one commander to reach another by voice, no matter where the other is. For ships operating "over the horizon" from an enemy coast, options for communicating with elements ashore are bulky and non-flexible (e.g., UHF SatCom, HF). Global PCS will change how Marines interact with the battlespace, because for the first time, reliable voice communications will be the rule, not the exception.

2. *The capability to provide transparent data flows across echelons, and between systems with bandwidth on demand.*

A wide area wireless data network, accessed by users from small, portable devices like laptop PC's and personal digital assistants, would facilitate cross-echelon data flows. The Marine Corps' main battlefield data network, TDN, will allow data transfer at the battalion level and above. Below this level, Marines could use short text messages to request supplies, call for fire support, or request medical assistance.

3. *The capability to provide voice transmissions to supersede data transmission during emergency conditions to fail-safe command and coordination actions.*

According to SEA DRAGON, digital data transfer is the preferred method of communications. Voice is also very important, especially in rapidly changing situations. The command and coordination system must allow for a voice "over-ride" capability so that people, not just computers, can understand each other. Some newer cellular systems allow "emergency" breakthrough service for critical calls. Others allow "priority" users the ability to get through to the called party on the very first try. As mentioned earlier, some software solutions to the priority issue exist for digital cellular networks.

4. The capability to precisely locate friendly and enemy forces.

According to FY 94 budget guidelines, Global Positioning System (GPS) service must be integrated into all combat vehicles and most electronic devices by 2000 [Ref. 15]. Any new communications architecture, especially wireless segments, must incorporate GPS directly. Integrated GPS should extend to the individual marine.

When it comes to precisely locating and reporting the enemy, laser designation devices that can determine the grid coordinates of a lased target are being tested. Any proposed command and coordination network must support the rapid transmittal of enemy sighting reports back to fire support assets in digitized format.

5. The capability to provide navigation assistance to all friendly units.

Again, an integrated, small form factor GPS capability with navigation software must be a part of any proposed portable computing or communications device.

6. The capability to execute command and coordination from either sea-based or shore-based MAGTF command elements, and to shift control without interruption of operational continuity.

Wireless LANs can provide this flexibility. The embarked marine command element may find it necessary to move to a shore-based configuration. Wireless LANs, with their easy reconfigurability, will allow Marines the same data intensive services they had aboard shipping. Traditional problems of electromagnetic interference and slower data rates will remain, however. Smooth shifts of control for commanders will be facilitated by personal communication devices. During the movement from ship to shore, the terrestrial or space based network will allow seamless connectivity to all levels of the MAGTF.

D. APPLICATIONS FOR TODAY'S MAGTF

In this section, the author presents some wireless applications that could enhance MAGTF capabilities, make jobs for certain individuals easier, save time, and reduce costs.

1. Shipboard Wireless LAN's

When a MEU receives a mission tasking from higher authority, the Navy and Marine staffs begin the rapid response planning process. This process involves the generation of numerous documents, graphics, lists, and other mission-related material. The shipboard location where these items are prepared varies from staterooms, the

wardroom, the Landing Force Operations Center, the Supporting Arms Coordination Center, and even the well-deck. Planners at all levels create files on numerous PCs that use different operating systems and different word processing applications. Marines must save these files on discs, and physically carry them to key staff individuals. The size of most amphibious ships means that time will be spent climbing ladders and searching for the right person to receive the data. Once received, the tedious process of combining and integrating all the various data for a command briefing is left to a few overworked individuals.

A shipboard wireless LAN, with numerous access points located in areas where the Naval and Marine staffs work, eat, and sleep, may facilitate the rapid planning process. File and document sharing, along with an internal messaging service, would allow planners to communicate and coordinate without the time consuming process of physical disk transfers. Many ships in the Navy inventory have been wired to support Ethernet-type LAN architectures. The author believes that on larger, newer amphibious ships, wireless LANs would save time and energy for crisis response planners.

2. Worldwide Paging for Liaison Officers and Advanced Parties

When MEUs deploy, there are many Marines who do not go aboard amphibious shipping, yet are vital to mission success. Supply individuals remain in CONUS to help with logistical support, like the rapid ordering of critical repair parts. Logistics liaison officers travel ahead of the ships to ports of call to arrange numerous agreements with

host nations. Aviation support elements, like KC-130 detachments that assist with in-flight aerial refueling missions, also stay close to the MEU at suitable airfields. Advanced parties often leave the MEU early to conduct area reconnaissance for operations ashore or to plan for the MEUs arrival at home port at deployment's end.

Each of the above examples involves key people who are not located with the MEU. A reliable worldwide paging service would provide a very responsive way to let key people know they are needed now. Instead of relying on "message traffic" that takes hours to send and respond to, a quick page from the MEU could let an individual know he should call a predetermined number to either contact the ships or listen to a new voice mail message sent by the ships.

3. Vehicle Tracking

OmniTracs, a wireless tool for tracking vehicle location in the US, is an example of an application that may prove useful in the future for deployed Marine Corps logistical efforts. OmniTracs consists of small radio transmitters mounted on trucks or delivery vehicles. The trucks also have built-in GPS receivers. The transmitter frequently sends out position information to large collection towers spread over North America. The signals are then routed back to a central site, allowing planners full visibility of where their vehicles are. They can tell if certain shipments are on schedule and can contact drivers with small text messages if there are changes in plans. [Ref. 8]

If a system like OmniTracs were set up for worldwide coverage, and Marine logistical units were equipped and trained with it, the responsiveness and flexibility of our combat service support would improve.

Good commanders are always concerned with logistics, because they realize food, ammunition, repair parts, fuel, and medical support are what make operations possible. One of the greatest concerns of MEU commanders is the ability for the combat service support element to repair broken, mission critical equipment. If a helicopter cannot fly because it needs a part, or a light armored vehicle can't run because its transmission is blown, certain military options disappear for the commander. A wireless pallet-level tracking system, similar to the one used by Federal Express and other rapid delivery services, could help logisticians track the location of critical parts from warehouse to user.

4. Other Applications

A fellow Marine officer is currently researching the feasibility of rapid dissemination of combat orders wirelessly [Ref. 19]. This information sharing would take place at all levels, including the fire team. Means of dissemination would include infrared, radio frequency, cellular, and traditional single channel.

Other areas where wireless services might benefit command and control include fire support coordination, well-deck and supply block applications, and forward observation.

E. MOBILE CELLULAR COMMUNICATIONS SYSTEM (MCCS)

MCCS is a Marine Corps funded program investigating the feasibility of using commercial off-the-shelf technology, with minimum modifications, to realize a mobile cellular communications system. The MCCS would provide rapidly deployable, digital voice and data communications as an overlay to existing assets in a mobile tactical environment. The MCCS was demonstrated in the fall of 1995 at the Joint Warrior Interoperability Demonstration at Camp Pendleton, CA. The author was given the opportunity to try voice, data, and video transfer using the system. The concept of employment for the MCCS is limited, in that it is intended to be a tool for high level commanders and their staffs only. The MCCS would overlay the existing Marine Corps communications architecture and would be interoperable with the Unit Level Circuit Switch, Mobile Subscriber Equipment, and host nation public switched telephone networks. MCCS is a broadband CDMA system with good characteristics for Low Probability of Intercept (LPI) and Low Probability of Jamming (LPJ) operation. Performance parameters include the ability to handle voice, data, and facsimile, 200 subscriber units per base station, and 10 km line of sight propagation range. For more information on this cellular technology investigation, including a good summary of some existing limitations of commercial-off-the-shelf cellular products, the reader is referred to the Requirements Division, C4I Branch, Marine Corps Combat Development Command, and [Ref. 20].

F. ADVANCED RESEARCH PROJECTS AGENCY (ARPA) WIRELESS INITIATIVES

The Advanced Research Projects Agency has conducted a Technology Reinvestment Program in cooperation with the US Army's Communications and Electronic Combat Command in the area of wireless digital communications. The purpose of this section is to explain some concepts for wireless technology employment being developed at ARPA.

ARPA has envisioned an overall architecture for future digitized battlefields. It will comprise "a mix of PCS and digital radios with both terrestrial and space-based communications to handle voice, data, and imagery." [Ref. 21] It will also possess mobile radio access points that will serve as cell sites and gateways to other communications media. In the ARPA concept, it's interesting to note the mix of commercial PCS type services and digital combat net radios. These will exist side by side, offering different capabilities and services to the warfighter, and increasing reliability and flexibility.

ARPA uses the term "PCS" broadly, to include conventional cellular, land mobile trunked radio, and direct access satellite systems. During the course of the technology reinvestment program, ARPA examined each of these services and evaluated their advantages and disadvantages. Additionally, ARPA conducted physical interoperability testing with portable PCS devices and the Army's Mobile Subscriber Equipment.

The mobile radio access points mentioned above are the most innovative idea yet presented for a robust battlefield wireless network. These devices would need to be small,

light, and survivable. Mounted on non-dedicated vehicles, they would go where lower echelon units go, providing users a wireless path back to the larger communications "grid." The access points would need little or no operator involvement to run, and would have to automatically self-configure as they moved around with respect to their users. ARPA suggests that satellites or long duration unmanned aerial vehicles could interconnect these forward access points with higher echelon wired assets further from the enemy. ARPA notes that rapid deployment, easy maintenance, and affordability are all very important aspects of any future wireless architecture.

ARPA's objective capabilities for future digital wireless communications architectures are listed: [Ref. 21]

1. Mobile
2. Robust
3. Survivable
4. Secure
5. Affordable

The characteristics of such an architecture are provided: [Ref. 21]

1. Secure, Digital, Networked system
2. High Data Rates
3. Modular, Multi-function nodes
4. Variable Bandwidth
5. Frequency/Waveform Agility
6. Mobile Compatibility with Global Information Infrastructure Standards
7. Ease of Deployment, Management, Usage.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

1. The Wireless Opportunity

This study began with an examination in Chapter I of the remarkable growth in recent years of wireless communications. Wireless communications bring robust services, flexibility, and mobility to users. The idea that wireless technologies could offer significant benefits to Marine Air Ground Task Forces was introduced. Additionally, the author suggested that commercial wireless applications support concepts envisioned in SEA DRAGON, a Marine Corps initiative for future warfighting.

2. Enabling Technologies and Their Applications

Chapters II, III, and IV were literature reviews of recent wireless technologies. Cellular, wide and local area data networks, and personal communications services will continue to see growth in usage and new applications. Chapter V briefly explained the concepts introduced in December, 1995, when the Commandant's Warfighting Laboratory (CWL) unveiled SEA DRAGON. The chapter also showed that certain wireless telecommunication networks, devices, and applications seem custom-made for the type of naval expeditionary warfare SEA DRAGON envisions. Most of the traditional

functions of command and control also stand to gain from the intelligent insertion of wireless services at the right places and times.

B. CONCLUSIONS

The following conclusions can be made in regard to Marine Corps employment of wireless technologies:

1. There are a number of Marine personnel, processes, and applications at the MAGTF that could benefit from commercially available wireless technologies.
2. The small size, low power, and cheap cost of new wireless devices will allow their easy introduction to the lowest levels in the hierarchy.
3. Future warfighting concepts like SEA DRAGON are well supported by the envisioned capabilities of a mature, global Personal Communications Network.

C. RECOMMENDATIONS

Areas related to the development of wireless applications for Marines that could greatly benefit by further research include:

1. Finding the right level in the Marine Corps command structure to place wireless devices and services.
2. Ensuring the devices, systems, and services we buy are logistically supportable for global deployment.
3. Security issues, such as cellular vulnerability to intercept, true privacy, and prioritization of calls.

4. Developing methods for the quality training and education of the personnel who will install, use, and maintain wireless systems.

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