detected signal quality independent of input RF signal amplitude. Equal-gain combining of RF signals can be used to improve performance by using pilot assisted cophasing circuits. RZ SSB equipment in prototype form can send and receive 19.2 kbps in a single 5 kHz channel, for a spectrum efficiency of 3.84 bits/sec/Hz.

6.5.4 Nonlinear

6.5.4.1 Constant envelope systems have approached 1.28 bit/sec/Hz, considered to be the limit for those systems. However, this advancement has been achieved largely through the use of more complex multi-level, partial response, and channel coding techniques, made possible by the improved performance of digital signal processing hardware.

6.6 Multiple Access Techniques

6.6.1 FDMA, TDMA, CDMA, and TDD are different channel access methods. Each has specific strengths and weaknesses. Because of these differences they are each best suited for various applications. FDMA is employed in narrowest-bandwidth, multi-licensed channel operation. TDMA is employed in exclusive license use, moderate bandwidth applications. CDMA is employed for widest-bandwidth in both single system applications such as cellular as well as distributed uncoordinated applications such as the Industrial, Medical, and Scientific band (ISM). TDD is employed to achieve full duplex operation in a single radio channel.

6.6.2 FDMA is the acronym for Frequency Division Multiple Access. In FDMA different conversations are separated onto different frequencies.

- Advantages: Maximizes licensable channels, simplest talkaround, simplest configurations, maximizes range
- Disadvantages: Limits maximum bit rate, duplexer required for full duplex, more stations for multi-channel sites, increases guardbands required.

6.6.3 TDMA is the acronym for Time Division Multiple Access. In TDMA different conversations are separated into different time slots.

- Advantages: Bandwidth on demand, minimizes stations for multi-channels, additional channel(s) for single licensee.
- Disadvantages: Range limited, exclusivity needed, talkaround complex, doesn't increase licensable channels.

6.6.4 CDMA is the acronym for Code Division Multiple Access.[17] In CDMA all conversations are separated by code space.

- Advantages: Possible increased capacity and reuse.
- Disadvantages: Significant bandwidth required, power control complexity.

6.6.5 TDD is the acronym for Time Division Duplexing Multiple Access. In TDD, a single radio channel is shared in time to achieve full duplex operation.

- Advantages: Full duplex without duplexer, maximizes licenseable channels.
- Disadvantages: Range limited, sensitive to timing.

6.7 Error correction coding

6.7.1 In radio systems the primary goal is to reliably deliver communications. In digital communications systems this equates to maximizing the ability to successfully receive digitally coded messages. In radio systems this is influenced by a variety of factors such as modulation sensitivity, receiver sensitivity, antenna gain, antenna height, transmitter power, etc. These measures may be impractical or prohibited by rules restricting effective radiated power.

6.7.2 Another method of improving signal reception that is specific to digital communications is to employ error control. A simplistic method to improve reliability is to send messages more than once. This has the serious disadvantage of increasing transmission time by the number of times the message is repeated. More efficient methods uses error control techniques that add bits to the data stream in a precise fashion. The extra bits, however, are placed in a precise mathematically-prescribed pattern at the transmitter such that complementary circuitry in the receiver can tell when an error has occurred, and determine what the correct bit value should be.

6.7.3 Two types of error control techniques are Forward Error Correction (FEC), which provides the ability to receive a correct message even in the presence of transmission errors, and error detection which provides the ability to detect the presence of errors within a transmission. Error detection is often employed in concert with Automatic Repeat reQuest (ARQ), which uses a return channel to request retransmission of corrupted data. FEC is more commonly used in voice communications or one-way data communications, while error detection and ARQ are more commonly used in two-way data communications.

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[17] CDMA is often referred to as spread spectrum, although spread spectrum generally includes CDMA as well as other techniques such as fast frequency hopping.

6.7.4 Adding extra bits (redundancy) to the transmitted data stream may at first seem unusual, as increasing transmission rates tends to REDUCE modulation sensitivity. However, as long as the improved success reliability more than compensates for the reduced modulation sensitivity a net gain in communications reliability can result.

6.7.5 Often, the added error correction information may amount to 50% or higher of the raw data rate, and significantly reduce the throughput. On the other hand, error detection typically requires only a modest increase in transmission overhead.

6.7.6 As described in the earlier section on specific services used in public safety land mobile radio systems, different methods of error control are traditionally applied to different services. Further, errors that escape the error control process vary in their effect based upon the nature of the communications. Voice or video decoders in the receiver can sometimes interpolate what a few missing bits should have been, while error induced text or numeric translation might have serious consequences. However as voice and video coders advance, each transmitted bit generally becomes more important, increasing the importance of error control techniques.

6.7.7 In addition to inadequate signal strength or excessive interference, the timing of the received bit energy also affects the bit error rate. In hilly and mountainous areas, and in urban settings, reflections cause multiple signal echoes to arrive at the receiver some time after the signal is received directly from the transmitter. If the directly-received signal is weak due to shadowing, the reflections can be stronger than the direct signal. The reflected propagation path lengths are longer than the direct path, and are often many in number. Such multipath effects are commonly recognized as "ghosting" in broadcast television. Much as ghosting can impair picture quality, multipath distortion can impair the ability of the receiver to determine if a received bit has the value of 0 or 1. Adaptive equalization, while not categorized as a form of error correction, can be used within constraints to alleviate the multipath problem, by determining what the multipath profile of the received signal is, and then adjust the timing of the received signal in the receiver such that the received signal is processed with the inverse of the multipath delay profile, canceling out the multipath effects.

Reference:
Roger Freeman, "Telecommunications Transmission Handbook," New York, John Wiley & Sons, Inc., 1991, p. 772-778.

6.8 Constraints on using various bands

6.8.1 Propagation issues (including air-to-ground).

6.8.1.1 Radio waves are blocked and reflected by mountains and buildings. These impairments greatly affect the working of mobile radio communications systems. The mobile radio channel presents one of the most difficult engineering challenges

seen in communications engineering. Providing reliable service to mobiles and portables throughout an agency's service area is extremely hard.

6.8.2 Multiband/Software radios

6.8.2.1 A software programmable radio is a radio in which the applications are configured under software control and in which the application, in whole or in part, is implemented by software resident in the radio. A software radio requires that he information is presented in a digital format for processing.

6.8.2.2 The software radio is seen by proponents as having several advantages. A number of applications can be hosted on the same hardware platform, which reduces the total amount of equipment required. The radio can be upgraded without changing the hardware for increased effectiveness and cost savings. New multimode/multiband capabilities can be achieved efficiently through dynamic allocation of radio assets in a multimode installation, including bridging among different air interfaces, which can facilitate interoperability in fixed and mobile applications.

6.8.2.3 Functional integration is used in the software radio to reduce the number of radio types into a single general-purpose programmable waveform processor. It is possible for multiple military, law enforcement, and commercial air interface standards to be implemented in a single radio, despite different physical layers (modulation, frequency bands, forward error correction), link layers (link acquisition protocols, link maintenance, frame/slot processing), network layers (network protocols, media access protocols, network time maintenance), upper layers (source coding), timebases and bandwidths.

6.8.2.4 The software radio can be compared with the personal computer (PC), with the PC's operating system functioning similarly to the software radio run time system, which runs applications under a high order language. The radio operating system is a set of utilities and interfaces that control the flow of information within the radio, and can be computed with the basic input output system (BIOS) of the PC. Unlike the personal computer, the software radio requires real-time processing to process a continuous signal, and requires low-latency processing for real-time acquisition responses.

6.8.2.5 The military is placing an increasing emphasis on digital radio technology because of its potential for lower cost, reconfigurability for multimode/interoperable communications. A current military project developing a software radio is the Speakeasy multiband multimode radio program. Hazeltine is the prime contractor, with TRW, Rockwell, Motorola, Martin Marietta, and Texas Instruments as major subcontractors. The goal of the program is to develop an open system architecture for radio service and demonstrate interoperability of multiple and simultaneous waveforms across a frequency range of 2-2,000 MHz.

6.8.2.6 Aspects of the program include study of a 2-2,000 MHz front end, implementation of a 2-2000 MHz (contiguous) RF subsystem, assessment of alternate processor technologies, multi-chip module integration, and wideband HF, VHF, and UHF antennas. Emphasized in the Speakeasy program is open bus standards to foster competition, third-party participation, evolutionary technology insertion, and reduced life-cycle costs. Also being studied is an open application programmer's interface, which eases design and integration, eases software maintenance, and encourages new applications and third-party participation.

6.8.2.7 There are many challenges to producing a practical and economical software programmable radio. Antenna systems must operate across a wide frequency range; a single multiband antenna systems is preferable to many antennas for different frequency bands. These antenna systems may be augmented with "smart" antenna technology to increase range and node density. Other enabling technologies under study include multiband power amplifiers, tunable preselectors, interference cancellers, low-noise synthesizers, wideband low noise amplifiers, wideband linear mixers, high- throughput digital signal processors, and smaller chip packaging.

6.8.2.8 Software radios are now much more expensive that hardware- based radios, with the market being confined to military, big business, and government applications. Over time, the cost of software radio enabling technologies will decrease as does the cost of digital signal processing chips, analog/digital and digital/analog converters, and memory and interconnection hardware. It has been projected that, within a few hardware generations, software radios will sufficiently leverage the economics of advancements in microelectronics, and provide seamless communications at a vest-pocket and palmtop level of affordability and miniaturization.

6.8.2.9 To summarize, as radio protocols and air interfaces become more complex, software-based technology solutions will play an increasing role. Software radios can be effective for facilitating interpretability by providing for multiple wireless standards at a single cell site, and for accommodating roaming mobiles crossing system boundaries.

References:
Patrick B. Tilley, Hazeltine Corporation, "Software Programmable Radios," Presentation to the Federal Communications Commission, November 2, 1995.

Joe Mitola, "The Software Radio Architecture," IEEE Communications Magazine, May 1995, p. 26.

6.9 Backbone System Elements

6.9.1 Most public safety mobile communications systems need a reliable backbone to carry signals to and from the base station sites to the control points. Historically, many of these links have been provided over microwave connections operated by

the public safety agency. Leased lines obtained from the local telephone companies have also been used.

6.9.2 We expect the future supply of backbone system elements to look much like the past but with two major exceptions. First, the lowest microwave frequencies (2 GHz) are no longer available for such backbone systems. Rather, such systems will have to be established at higher frequencies where rainfall attenuation may pose a greater problem. Such propagation problems may restrict the length of microwave hops and raise the cost of new systems.

6.9.3 We also expect fixed microwave systems to continue to improve and additional digital capabilities are built into the radios. Modern microwave radios already allow for integration of their systems into current technology operations and management systems (OMS). We expect such trends to continue. Similarly, we expect that microwave radios will evolve to support the latest signal formats (e.g. ATM).

6.9.4 The second exception is the supply of facilities by the local carriers. Historically, only one firm, the local telephone company, provided telecommunications services for hire. However, changes in law and technology have led to the entry of new competitors in many markets and the probability of extensive further entry. We expect that most urban areas will have several firms offering ground-based fiber connectivity. Firms offering such services are now known as competitive local exchange carriers (CLECs). Such firms include MFS, Teleport, local cable companies, and even AT&T and MCI. Many of these fiber systems will use a ring architecture, allowing service to continue even if the fiber is cut at one point. Such backup capabilities give modern fiber rings substantially higher reliability than traditional copper wire telephone services. It is reasonable to expect that fiber rings will provide connectivity to many public safety communications centers and to many of the major antenna sites. Modern (1996 state-of-the-art) fiber system provide the most capacity of any widely used communications technology. Operational fiber systems carry gigabits per second of capacity on a single fiber. The theoretical capacity is far higher. Considering all these factors it is reasonable to conclude that these commercial fiber systems could provide valuable backbone alternatives for many public safety communication needs. However, the use of any ground-based carrier for public safety systems in earthquake-prone areas may be undesirable. In contrast, in areas affected by hurricanes, such as the southeastern coastal areas, an in-ground fiber network could be preferred.

6.9.5 Fiber is another option for high-density ground-based systems. The long distance carriers abandoned microwave for fiber not only because fiber had greater capacity and a lower error rate but because it was a less costly technology. In most fiber systems the largest cost is for the installation of the fiber itself. If municipalities have access to utility rights-of-way or utility poles, this cost can be markedly lowered. Self provision of fiber systems by public safety agencies will remain a valuable alternative in the years to come.

6.10 Performance Modeling and Verification

6.10.1 As wireless communications systems evolve, the complexity in determining compatibility among different types of such systems increases. Geography, frequency, modulation method, antenna type, and other such factors impact compatibility.

6.10.2 Spectrum managers, system designers and system maintainers have a common interest in utilizing the most accurate and repeatable modeling and simulation capabilities to determine likely wireless communications system performance. With increasing market competition in wireless communications systems, in terms of both technical approaches offered and the number of entities involved, a standardized approach and methodology is desirable for the modeling and simulation of wireless communications system performance. Such an approach should be technology neutral, and consider a variety of technical practices at all frequency bands of interest.

6.10.3 In addition, subsequent to wireless communications system implementation, validity or acceptance testing is often an issue subject to much debate and uncertainty. Furthermore, long after a system is in place and optimized, future interference dispute resolution demands application of a unified quantitative methodology for assessing system performance and interference.

6.10.4 The Telecommunications Industries Association (TIA) Land Mobile Radio Section TR-8 WG-8.8 Technology Compatibility Committee is working under a charter and mission statement to address the following technical challenges:

- Accommodating narrowband/bandwidth-efficient technologies likely to be deployed as a result of the Commissions "Spectrum Refarming" efforts;

- Assessing and quantifying the impact to existing analog and digital technologies from new narrowband/bandwidth- efficient digital and analog technologies;

- Assessing and quantifying the impact to new narrowband/bandwidth efficient digital and analog technologies from existing analog and digital technologies; and

- Addressing migration and spectrum management issues involved in the transition to narrowband/bandwidth-efficient digital and analog technologies. This includes developing solutions to the spectrum management and frequency coordination issues resulting from channel splitting from 25 kHz to 12.5 kHz, and from 25 kHz or 12.5 kHz to 7.5, 6.25 kHz or 5 kHz channel

spacing, as well as increases in capacity of existing channels to provide equivalent narrowband spectrum efficiency.

6.10.5 To accomplish these objectives, the WG-8.8 Committee is working with the Institute of Electrical and Electronic Engineers (IEEE) Vehicular Technology Society's (VTS) Propagation Committee. The IEEE Propagation Committee's contribution to this technology compatibility effort is in the area of supporting development and adoption of standard two-dimensional (2D) and three-dimensional (3D) electromagnetic wave propagation models, a diffraction model, and standards pertaining to the selection of terrain and land use data bases. The propagation related effort shall be generalizable to the electromagnetic wave propagation modeling and simulation of both current and future land mobile wireless systems.

6.10.6 WG-8.8 has noted a TIA commitment to the spectrum refarming effort, a request from APCO Automated Frequency Coordination, Inc. for post refarming technical support, and a request for expansion of the Committee!s work by the Land Mobile Communications Council (LMCC). The WG-8.8 effort has focused on the following:

- Establishment of standardized methodology for modeling and simulating narrowband/bandwidth efficient systems operating in a post "Refarming" environment;

- Establishment of a standardized methodology for empirically confirming the performance of narrowband/bandwidth efficient systems operating in a post "Refarming" environment; and

- Aggregating the modeling, simulation and empirical performance verification standards into a unified "Spectrum Management Tool Kit" that may be employed by frequency coordinators, system engineers and system operators.

6.10.7 The Committee's draft document, entitled "On the Standardization of a Methodology for the Modeling, Simulation and Empirical Verification of Wireless Communications System Performance in Noise and Interference Limited Systems Operating On Frequencies Between 30 And 1500 MHz," is near completion, and is intended to ultimately serve as a standard to define the compatibility criteria of the various different modulation types using terms consistent with overall TIA and IEEE land mobile efforts.

6.10.8 The expressed purpose of the document is to define and advance a scientifically sound standardized methodology for addressing technology compatibility. This document provides a formal structure and quantitative technical parameters from which automated design and spectrum management tools can be developed based on proposed configurations that may temporarily exist during a migration process or for longer term solutions for systems that have different technologies.

6.10.9 The document puts forth a standardized definition and methodology for a process for determining when various wireless communication configurations are compatible. The document contains performance recommendations for public safety and non-public safety type systems that should be used in the modeling and simulation of these systems. The document also attempts to satisfy the requirement for a standardized empirical measurement methodology that may be useful for routine proof-of-performance and acceptance testing and in dispute resolution of interference cases that are likely to emerge in the future.

6.10.10 To provide this utility requires that various performance criteria be defined for the different modulations and their specific implementations by specific manufacturers. Furthermore, sufficient reference information is to be provided so that software applications can be developed and employed to determine if the desired system performance can be realized.

6.10.11 Wireless system performance will be modeled and simulated with the effects of single or multiple potential distortion sources taken into account. These sources include:

- Co-channel users
- Adjacent channel users
- Internal noise sources
- External noise sources
- Equipment non-linearities
- Transmission path geometry
- Delay spread and differential signal phase

6.10.12 Predictions of system performance will be based on the desired RF carrier versus the combined effects of single or multiple performance-degrading sources. Performance will be based on a faded environment to more accurately simulate actual usage and will consider both signal magnitude and phase attributes.

6.10.13 It is anticipated that the document will serve as the standard reference for developers and suppliers of wireless communications system design, modeling, simulation and spectrum management software and automated tools.

6.10.14 It is envisioned by WG-8.8 that future wireless systems that employ the WG-8.8 standard in the design, modeling, simulation, and implementation processes will benefit from consistent performance as designed. Furthermore, the Committee expects that spectrum management based upon the same precepts and standard will not only be "consistent" with the designs submitted, but will be more accurate and more flexible accommodating each unique set of conditions rather than relying upon generalized tables and "rules-of- thumb."

6.10.15 Since the migration from the analog world of today to the digital future will be gradual, it is anticipated that there will be additions to the collective knowledge

base. Therefore, on a regular basis, initially on an annual basis, the WG-8.8 document will be revised based upon the receipt of relevant additions and/or corrections. Updates will also be issued that reflect refinements as requested by the body of systems designers, and spectrum managers who will ultimately be the users of this standard.

7.0 COMMERCIAL SERVICES — TECHNOLOGICAL CAPABILITIES AND DEVELOPMENTS

7.1 Background

7.1.1 Many present and future technological capabilities are (or will be) developed for large commercial service providers or government systems. Commercial services presently complement those which are developed by public safety agencies, where any combination of user density, offered load, geographic area, or other similar factors do not justify development of dedicated systems or expansion of existing networks.

7.1.2 Commercial services are motivated to derive the maximum utilization and efficiency from large systems and limited spectrum. As market penetration increases, carriers are more inclined to improve coverage, expand capacity, and provide additional features to allow (encourage) higher utilization and increased income.

7.1.3 Public safety agencies often utilize the existing commercial services as an adjunct to the systems which they have developed to provide their essential services. Those essential services (such as voice dispatch) may have unique operational, availability, or security needs, or may be more economically feasible and desirable. In the future, as usage of and dependence on these services increase, public safety agencies might elect to "partner" with commercial services (for customized services or features), or develop their own systems utilizing similar technologies. Their decision will depend on many factors, including cost comparisons, security, reliability, priority availability and access, and restorial, service area and feature requirements, and system administration.

7.1.4 Likewise, as regulatory and technological changes are made, commercial systems will likely evolve to provide universal services such as voice dispatch, data services, and electronic messaging. These services may also address the other issues above to meet the demands of their subscriber base.

7.2 Mobile Satellite Systems

7.2.1 Commercial Mobile Satellite Systems started in the 1970's when COMSAT offered service in the Atlantic for shipboard communications through its MARISAT system. This was subsumed into the International Maritime Satellite Organization (INMARSAT) when it was formed. In the early days, INMARSAT installations

cost about $50,000 each, and tariffs were $10 per minute. Both have been reduced significantly in recent years. INMARSAT became global and ultimately changed its name to International Mobile Satellite Organization (INMARSAT was retained). It now offers worldwide aeronautical, land and maritime mobile telecommunications. Some interim operations have been allowed in the U.S., but with commencement of mobile satellite operations by the American Mobile Satellite Corporation (AMSC), INMARSAT will not be allowed to provide land mobile communications in the U.S. because there is a domestic alternative with an exclusive license.

7.2.2 Recently, INMARSAT created another organization, ICO Global Communications to provide non geostationary mobile satellite communications from an Intermediate Circular Orbit (ICO). ICO has received substantial investments and awarded satellite construction contracts to Hughes Space and Communications International. The system will include two orbits of five operational satellites in two different 40 degree planes with one in orbit spare satellite for each plane. Satellites will orbit at 10,355 kilometers. Licensing issues for service in the U. S. are not resolved.

7.2.3 In the U. S., three "Big LEOs" have been licensed by the FCC. Big LEO means satellites in low or medium earth orbit operating above 1 GHz and providing both voice and data. "Little LEOs" operate below 1 GHz and provide data service only. The three big LEO licensees are: Motorola's Iridium, Loral/Qualcomm's Globalstar, and Odyssey Telecommunications International, Inc.'s Odyssey where TRW Inc. and Teleglobe Inc. are the founding shareholders. Mobile Communications Holding, Inc.'s Ellipso has a pending application before the FCC to join the other three.

7.2.4 It is expected that all the Big LEOs plan to offer service late in this century or early in the next with dual mode satellite\cellular telephones. Currently, ORBCOMM is the only Little LEO in operation. It has two satellites in orbit, and beta testing is in progress. To provide continuous coverage over the U.S., 26 satellites are necessary. This constellation is planned for full deployment by the end of 1997. As these systems are placed in operation and their user terminals tested in quantity, much more will be learned about their ability to support emergency communications.

7.2.5 While Mobile Satellite Systems may be able to provide some public safety-related communications capability, concerns have also been expressed that both Big LEOs and Little LEOs may infringe on current public safety spectrum. Some Big LEOs are seeking radio frequencies in the 2 GHz bands now used for public safety microwave operations, and Little LEOs have advocated sharing UHF, VHF, and 800 MHz land mobile spectrum.

7.2.6 Constellations/coverage

7.2.6.1 Satellite systems support thousands of voice channels and in many spot beams are used so that some frequency reuse is possible. Satellite services are completely digital thereby facilitating National Security Agency encryption systems,

as well as, commercial voice privacy alternatives. Public safety agencies and others may lease dedicated channel(s) for their exclusive use. Dispatch, push-to-talk, and "party line" talk group services are available. Voice, data, fax, and location services are possible through automatic connections to the public networks. Dual mode satellite/cellular, satellite only, transportable and fixed site systems are available. In some cases, duplicate coverage will be supplied. Capacity sharing and backup support agreements are provided so there will be no single point of failure in the space segment.

7.2.6.2 The public safety community would not require dedicated satellites costing billions of dollars. Dedicated satellite systems are unnecessary. Future public safety systems can rely on the public switched and data networks and commercial mobile satellite systems to avoid costly infrastructure investments. Even DOD is moving in this direction. Public safety organizations cannot create the management structure, obtain regulatory approval and raise money for dedicated satellite systems. A better approach is to follow and influence developments of these systems, use them, and factor requirements into existing and future systems.

7.2.6.3 Dual mode satellite/cellular radios cost about $2500 per unit; the per minute charges are $1.49 or less including terrestrial long distance charges. Talk groups can be established for $100 per month, and practically unlimited users may join them for $70 per month. The $70 per month allows dispatch and unlimited talk time for users. An organization could buy 1000 radios for $2.5 million and operate them in 100 talk groups for about $80,000 per month. Up to 35 users per circuit can be accommodated -- so 100 talk groups per 1000 users is conservative. On the AMSC system, a user may belong to 16 different talk groups. A state with such a system could deploy units gathered throughout the nation to respond with units to an Oklahoma City type disaster. Arriving units would be ready to communicate anywhere, anytime, provided there is a clear view to the south. Talk groups could be rearranged over the air in minutes without touching the installed equipment. The GPS interface could provide position locally or to transmit it to distant control stations for automatic tracking of responders. Differential GPS corrections are available via the AMSC system to provide accuracies better than 10 meters.

7.2.7 Priority Access

7.2.7.1 Priority access to the mobile satellite system may be assured in several ways. Channel priorities may be implemented by techniques ranging from access to the next available channel to preempting existing users; however, preemption is fraught with practical and public relations difficulties. In the early years of operation where capacity limit problems are not expected, setting aside a few channels for emergencies may be the desired approach. With these as an initial cushion, the highly dynamic nature of calls on and off the systems will allow timely access to channels as needed.

7.2.7.2 Priority designations will be lost when communications enter the Public Switched Telephone Networks as they are currently configured unless dedicated lines are provided between gateway stations and public service agencies. Overloaded telephone systems during an emergency are common. Priority accessvia the PSTN or dedicated lines will be required for an effective emergency system. One such method is "GETS", the Government Emergency Telecommunications System.[18]

Reference:
White Paper "Mobile Satellite Systems," February 27, 1996, prepared by M. Edward Gilbert, RADM, USCG (Ret.), President, Gilbert & Associates, on behalf of American Mobile Satellite Corporation (AMSC).

7.3 Cellular Telephone Systems

7.3.1 Cellular telephone systems are an outgrowth of, and improvement on early mobile telephone systems. Those early systems relied on a small number[19] of channels, each served by a single base station covering the widest possible geographic area. Even though the communications were between two parties (usually, only one of which was mobile), "blanket coverage" was provided to the entire area. Obviously, this type of system had serious capacity limitations, and was not spectrum efficient because it limited channel reuse.

7.3.2 The concept of cellular systems is to utilize a number of fixed sites, arranged and connected as a network of "cells." Lower antenna heights are used; and transmit power is limited and controlled dynamically to the lowest possible level, while ensuring quality communications. All sites are connected to the public switched network and controlled from a central location, typically referred to as the mobile switching center (MSC) or mobile telephone switching office (MTSO). As power and antenna heights decrease, the smaller coverage area of each cell allows greater channel reuse. The lower power and closer proximity to subscribers also makes portable operations more feasible.

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18 The Government Emergency Telecommunications Service (GETS) supports national security and emergency preparedness (NS/EP) requirements for use of the public telephone network by Government departments, agencies, and other authorized users. Developed in response to White House tasking, GETS provides authenticated access, enhanced routing, and priority treatment in local and long-distance telephone networks. GETS access is through a simple dialing plan and personal identification number (PIN) and provides switched telephone service that can be used for secure or unsecure voice and voice-band data services. Its implementation consists primarily of software enhancements to the signaling networks and switching systems of the major communications carriers, both local and long distance. As such, the program is leveraged to provide maximum capability at a minimum investment, to exploit technology improvements in the installed systems, and to provide NS/EP support with an inexpensive "service", rather than an expensive, dedicated "system."

19 Thirty-four (34) channels were available to telephone companies, among three services in three bands, with a maximum of 12 channels available in any system. The largest systems typically had no more than six channels, owing to overlapping systems which covered adjacent geographic areas.

7.3.3 Smaller coverage areas mean that traveling subscribers might lose service during a call. To counter that problem, each cell in the system continuously monitors call quality, and when necessary, hands ongoing conversations off to a site which can provide better service at the mobile subscriber's present location. These hand-offs typically require less than 0.3 seconds, and are barely noticeable to either party.

7.3.4 In rural areas, cells may be designed with much larger coverage areas, and initially equipped with relatively few channels to serve the small number of users. Doing so allows the initial investment in infrastructure to be scaled, making initial market penetration easier to accomplish. As the number of subscribers and demand for service increase, additional channels and cells may be added, and the coverage area of existing cells can be reduced. As traffic density increases in high use areas, cells may be subdivided further into sectors, but served from the same site using directional antenna systems (commonly referred to as cell splitting).

7.3.5 Several years of delay were experienced as cellular technology and the regulatory framework for its implementation were developed. As a result of the regulatory framework, cellular carriers were prohibited from providing other services such as voice dispatch and one-way paging; mostly because of concerns over unfair competition and market advantage. Even though many services could have been implemented technically, the equipment, systems, and software developed under initial regulatory constraints is still not capable of providing many needed services.

7.3.6 Initially, 40 MHz was allocated for cellular services from spectrum which had previously been allocated as UHF television channels.[20] This spectrum was organized into 30 KHz duplex channels, with all 666 initially envisioned for assignment to a single service provider in each geographic area. Final regulations divided the spectrum into two blocks of 333 channels each, to encourage competition through a duopoly of services. Over 700 cellular geographic service areas (CGSAs) were defined, with 305 metropolitan statistical areas (MSAs) containing the most populous cities. The remaining areas are considered rural service areas (RSAs). One of the blocks (designated B) was set aside in each "market" area for the wireline common carrier (telephone company). The other block (designated A) was assigned[21] to interested common carriers which did not provide wireline services to that same market. In 1986, an additional allocation of 5 MHz (166 channels) was divided equally between the two existing blocks.

7.3.7 Service requests, call supervision, and mobile "paging" calls are accomplished on 21 setup channels in each block (313-333 and 334-354). The A and B band setup channel blocks are contiguous so that synthesizers can scan quickly between systems

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20 Parts of television channels 73-77, and 80-83.

21 Initial assignments were made by comparative hearings, but the large number of speculators delayed the licensing process and deployment of systems. Later assignments were made by lottery drawing, from a pool of qualified applicants in each market.

in either band. Mobile subscribers use a self locating scheme, where inbound requests are made on the setup channel having the strongest received signal (hence probably the best, if not closest server). Because of this approach, a broadcast "paging" message must be sent from each cell's setup channel for each outbound call. The called mobile responds through the best serving cell (which it is already monitoring), making its approximate location in the system known. Because a large majority of calls are initiated from mobile subscribers, the inefficiency of this paging method does not negatively impact system performance.

7.3.8 Current cellular systems have several attributes which limit their appeal to public safety users. As mentioned earlier, cellular systems were not developed to provide dispatch services. Subscribers must be registered in the system, and the unique identification of the desired unit(s) must be known to the system and calling party. Broadcast type communications are not supported, so it isn't possible to make an "all call" to any unit available to respond. Because of the full duplex nature of subscriber equipment (and lack of a push-to-talk button), a conversation between mobile subscribers requires one "bearer" channel for each unit involved. Talk group calls between multiple units could easily consume all available channels in a cell. One of the greatest concerns to public safety agencies is the lack of priority access and availability to their units. A subscriber's service options may also be limited if the available carriers adopt incompatible technologies to improve spectrum efficiency or increase capacity. Direct system monitoring and unit access control is not available to managers, making administration and cost control difficult.

7.3.9 Cellular systems are designed to provide adequate capacity during most peak periods, but they are still vulnerable to overload and abuse[22] during large incidents or special activities. Cellular systems have also suffered significant loss of service or capacity (due to hardware failure) during the initial hours of major natural disasters. With the proposed cellular priority access scheme, state and local government users would be limited to no more than level three (of five) access. Most proposed priority access schemes will not preempt calls in progress. To do so presents a risk, but as long as preemption is prohibited, callers may continue to abuse the system once access is gained. Mobile systems are also available and marketed to television broadcasters, which utilize six simultaneous cellular connections to send "video feeds" back to their studios from the field. One minute of full motion broadcast quality video is provided for each eight minutes of connect time. The presence of such anonymous users at a public safety incident can severely impact the grade of service provided by any cellular system.

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22 During disasters, "non-public safety" cellular subscribers have been known to access a channel, make a call to their "home base," and keep the connection open continuously (placing the handset in the seat of a vehicle), so that it would be available when needed. Even when accumulating usage fees over several hours, some deem it a small price to pay to ensure availability in a competitive environment.

7.3.10 In spite of the limitations mentioned here, cellular telephones are able to meet certain aspects of public safety communications needs. For instance, they are useful for communications between public safety field personnel and the public being served. Cellular telephones can also provide communications with other adjunct members of the public safety system (regional or specialty service facilities, off-duty specialists, security personnel, etc.). Contact with these adjunct members might be difficult or impossible otherwise. The need rarely justifies the associated fixed equipment, or the compromises in security necessary to provide access. Personnel can use cellular telephones when they are out of their normal service (coverage) area, or when in areas that cannot be economically served by the primary system.

7.3.11 Cellular telephones are also preferred by many public safety agencies as an alternative to carrying telephone interconnect traffic (and consuming large percentages of available capacity) on essential voice channels. Some public safety agencies use cellular phones to backup wireline telephone trunks, or to provide dial tone on demand at itinerant locations where little notice is given. These uses are likely to be effective only during localized hardware or trunk failures or isolated needs; not during widespread outages of the public switched telephone network.

7.4 Cellular Digital Packet Data (CDPD)

7.4.1 Even with the proliferation of analog cellular systems, circuit switched communications are still not popular for general data applications. Circuit switched usage fees are based on connect time, not data volume. Short interruptions during handoffs between cell sites are often imperceptible during voice conversations, but most data communications equipment sends (and expects to receive) a continuous carrier signal. Special precautions must be taken to prevent loss of established connections, and to retransmit information lost or impaired during brief interruptions or fades. Often, digital message traffic is short and sporadic, but frequent. It is not cost effective (or efficient) to maintain an established connection for sporadic data bursts with a low average utilization. Alternatively, the time to establish a connection may exceed by magnitudes, the duration of the messages to be sent.

7.4.2 A standard method was devised to allow analog advanced mobile phone system (AMPS) cellular voice channels to carry high speed packet switched data communications during otherwise idle times. Cellular Digital Packet Data (CDPD) systems were developed to transport data to (or between) cellular users without the need to set up a traditional call. Since communications are "connectionless," usage is determined by traffic volume instead of session duration. The bursty nature of many data systems allows messages to be packetized and transported during those idle times, with little or no perceptible impact on response times.

7.4.3 CDPD systems can be implemented with no additional spectrum for control or traffic channels, and relatively little additional infrastructure. Since systems can be overlaid on existing cellular networks, work to increase utilization, and generate

additional revenue, they are very attractive to carriers. They are also attractive to users, since wireless data communications can be obtained over a well defined coverage area, with much lower (or no) capital costs for infrastructure. A group of CDPD users may also share fixed end interface equipment (where necessary), with limited connection to the cellular network. This could make the service affordable for smaller users who would not otherwise be able to justify the fixed equipment cost.

7.4.4 CDPD systems support a "raw" data rate of 19.2 kbps. The systems monitor the control channel in their own cell, and "sniff" voice channel activity in adjacent cells, utilizing only idle channels. If the CDPD system detects assignment of, or activity on a voice channel that it is using, it interrupts its own data stream on the channel immediately, and the next packet is passed over another idle channel. The systems are built on an Internet Protocol (IP) foundation, and applications may use either the Transmission Control Protocol (TCP) or the User Datagram Protocol (UDP). Transmission of data is transparent, allowing encryption of user information, if desired.

7.4.5 System developers are able to easily adapt most TCP/IP based software applications for CDPD transport. Care must be taken, however, since some TCP/IP based software applications are verbose, and developed considering a relatively usage insensitive cost model. As messages get smaller, they become a smaller percentage of the total transmission. Characters associated with session control, acknowledgment, flow control, and packet retransmission are passed through on CDPD systems, along with the actual message, and the customer may be charged for those additional characters. Pricing packages vary greatly among providers, and should be analyzed carefully when considering the use of CDPD. It is important for users to understand the impact of different pricing structures in deciding which transport method to use. Users who are planning to purchase or develop software applications should make sure that TCP is used only where appropriate.

7.4.6 The alternative (UDP), provides an "unreliable" delivery mechanism. Reliability in this sense relates to the fact that data packets may be lost; errored; duplicated, or improperly sequenced (by arriving through different traffic pathways); or dropped by message overruns and the lack of flow control at the receiving end. When using UDP, reliability is the responsibility of the application program.

7.4.7 Some economies can be gained for "chatty" applications (such as automatic vehicle location) by using UDP, but additional care must be taken by the application software to ensure "reliability." For instance, if vehicle location packets are serialized before transmission (and the sequence number sent as part of the user's location information message), the receiver may still detect missed packets. If location information is being sent every 30 seconds, an occasional missed packet can be detected, but will probably not affect long term reliability, and need not be retransmitted. If location information is received out of sequence, the problem can be detected and handled by the application program. If location information from

a vehicle is interrupted unexpectedly for an extended period of time, that too can be easily detected and reported by the application program. These methods allow one-way inbound messaging, with outbound messages necessary only for exception handling.

7.4.8 Because UDP and TCP both rely on IP, they can both be used (concurrently) for different applications. TCP can support mobile data applications, while UDP serves other less critical needs, possibly with higher information content. Applications may also switch between TCP and UDP, depending on the current status of the user, or whether the messages are routine or urgent.

7.4.9 Some "traditionally wired" networks also poll all users on a frequent basis to enquire whether they have traffic, and to ensure connection. "Spoofing" can be provided by the wireline interface to handle actual traffic on the wireless side, and act as an agent for the wireless equipment. It will "answer" enquiries from the wireline network without generating additional unnecessary traffic on (or costs for/delays in) the wireless network.

7.4.10 Hybrid systems are also under development which can operate in a packet switched mode (CDPD) for small bursty transactions, or in a circuit switched packet mode (still IP based, but with an established and guaranteed connection) for larger volumes or more time sensitive information.

7.4.11 Even though CDPD equipment does not rely on a connection, it does rely on the availability of an idle channel for brief periods. As channel utilization approaches unity, the availability of idle channel time diminishes. Without some method to provide priority access, CDPD users are subject to the same delays or unavailability of service during peak periods that traditional voice users encounter. Delays may also result in increased CDPD traffic, since packets may be properly received, but not acknowledged within the timeout window. If public safety providers are to rely on this technology, some method of priority access (or dedicated capacity) must be provided.

7.5 Personal Communications Services (PCS)

7.5.1 Action taken at the World Administrative Radio Conference (WARC) of 1992 upgraded to primary status, future public land mobile telecommunications systems (FPLMTS) between 1.7 and 2.6 GHz. As a result, the FCC made approximately 140 MHz of spectrum available for Wideband Personal Communications Services near 2 GHz, with more held in reserve, possibly for future mobile satellite service. Additional channels were reallocated in the 900 MHz band, referred to as narrowband PCS.

7.5.2 The Federal Communications Commission devised a plan to auction the available spectrum to interested parties, who could then provide personal communications services (PCS) for public benefit at a profit. By auctioning the spectrum, the FCC

avoided the problems of earlier assignment schemes, curbed speculation, generated government revenue, and motivated auction winners to develop systems quickly and maximize spectrum efficiency. No standard technology was mandated for these services, because the FCC felt that service providers should be free to employ the technologies that are most appropriate for their service, market and investment goals.

7.5.3 The FCC designated four different levels of "marketing" areas. The first level is a nationwide assignment. The remaining areas of operation, or "markets" are derived from the 123rd edition of the Rand-McNally Commercial Atlas and Marketing Guide and adopted for use with few exceptions and changes. The United States is divided into 51 Major Trading Areas (MTAs) and 493 Basic Trading Areas (BTAs). BTAs are not distinct from MTAs, they just represent a finer detail of local market areas. The FCC then created five regional markets, defined by the MTAs that they encompass.

7.5.4 In the 900 MHz band, the FCC reallocated 26 "narrowband" channels for PCS. The channels are divided into four distinct groups. The first group includes 11 channels, which are allocated on a nationwide basis. The second group of six channels will be licensed in each of the five designated regions. Seven channels will be licensed in each of the MTAs as described earlier. The two remaining channels will be licensed in each of the BTAs. No single licensee will be allowed to aggregate more than three channels.

7.5.5 Three types of channels were developed. The first type is a two-way, paired 50 KHz channel with 39 MHz transmit-receive spacing, which can support full two-way voice or data messaging. Asymmetric paired channels are allocated with a 50 KHz "forward frequency" and 12.5 KHz low speed "return frequency" for limited responses from subscriber units. Those channels have approximately 29 MHz transmit-receive spacing. The final type of channel is a 50 KHz unpaired channel intended for one way-paging or messaging.

7.5.6 The FCC created seven blocks from 140 MHz in the 2 GHz band. Six of the blocks contain upper and lower allocation sub-blocks, separated by 80 MHz. The A and B bands were each allocated 30 MHz, to be assigned in each of the MTAs. The C band was allocated 30 MHz, for assignment in each of the BTAs to designated entities (minority and small business entrepreneurs). The D, E, and F blocks were also allocated 10 MHz in each of the BTAs. The D and E blocks are available for assignment to any eligible bidder, but available to the incumbent cellular carriers (whose participation is otherwise limited).[23] The F block is intended for assignment to designated entities as described above. Finally, the unlicensed UTAM block is one contiguous 20 MHz block of spectrum between the two sub-bands. UTAM

[23] A cellular carrier may be licensed to provide PCS in an area, if there is less than 10% overlap between their cellular market area, and the BTA or MTA license that they would hold. In the case of an overlap of more than 10%, cellular licensees are limited to one 10 MHz license in that same area.

systems are likely to be private wireless PBX systems, wireless local area network devices, etc.

7.5.7 Due to propagation characteristics of the band, most 2 GHz systems are expected to be developed using a micro-cellular architecture, serving the most populous metropolitan areas using a network of closely spaced stations. Service in lower demand areas will be provided by systems with antenna heights, output power levels, and coverage areas which are more in line with today's cellular systems. Both are intended to provide subscribers with enhanced features and untethered access to the public switched telephone network.

7.5.8 Services provided by PCS licensees will vary, but can range from consolidating what are now separate services (cellular, paging, wireline telephone, mobile data), to the provision of very specialized services. For instance, vending machines have been equipped with wireless devices to provide information on remaining inventory, total receipts, empty change bins, mechanical problems, or burglary. The device could be supported by a wireline circuit, but the mobility of the vending machines — which are often moved regularly from one location to another — is limited as a result. The "wireless solution" allows flexibility, freeing the device from the limitations of wireline networks (physical connections and identification constraints). A PCS device can thus reduce the need for unnecessary trips to vending machines on a route, while improving the level of service; a highly specialized service.

7.5.9 Personal Communications Services are under development as of this writing, but indications are that the successful licensees will select and implement differing technologies, even for similar systems in adjacent areas or bands; thus limiting not only competition, but interoperability and mobility as well. Different systems may utilize different access schemes (TDMA, CDMA, FDMA as described elsewhere) and system architectures, limiting service options for owners of subscriber equipment. For instance, the sub-bands of licensed blocks are intended to allow frequency division duplex, but they could be implemented using time division duplex schemes. Inexpensive subscriber equipment will likely have limited interoperability. Units providing service option selections may be more expensive, because of the need to support multiple technologies.

7.5.10 The lack of standards is likely to impede the ability of some PCS users to roam nationwide using "local subscriber equipment," or to select between carriers to the extent that current cellular telephones allow. PCS systems will be able to provide enhanced local access without the provisioning delays, costs, or maintenance required by outside cable plants. PCS providers will probably enter the competitive access provider (CAP) market, but likely target similar services (cellular) in urbanized areas; initially concentrating on the CAP market only in underserved areas where they can be more competitive.

7.6 Special Mobile Radio/Enhanced Special Mobile Radio (SMR/ESMR)

7.6.1 Specialized Mobile Radio (SMR)

7.6.1.1 Specialized Mobile Radio (SMR) services were established by the FCC in the mid-1970's with the allocation of a portion of the 800 MHz band for private land mobile communications system. SMR services succeeded the "community repeater" shared service prevalent on other bands with more advanced offerings usually associated with a minimally-featured trunked radio system, sometimes with telephone interconnect service. SMR systems are characterized by a single high-power, high-elevation base station for maximum coverage. Today's SMR market is dominated by a quasi- open platform based on the format designed by one manufacturer. Current trends reveal large operators who have acquired many 800 MHz SMR operations.

7.6.1.2 Public safety has used SMR as a primary dispatch service with varying degrees of success. The versatility of the SMR industry and its relationship to public safety because of the dependence of both on dispatch as a primary service will continue to be attractive as the SMR industry becomes more sophisticated and integrated. These attributes may provide an alternative for public services when the specifications for this industry are more consistent and interoperable

7.6.2 Enhanced Specialized Mobile Radio (ESMR)

7.6.2.1 The latest systems, based on digital technology, are known as Enhanced SMR (ESMR), or "wide area," SMR systems. ESMR systems are typically characterized by a network of base stations in a cellular-type configuration. They are several times as spectrum efficient as SMR systems and offer enhancements including the consolidation of voice dispatch, telephone interconnect and data services into a single portable/mobile subscriber unit. ESMR services are most prevalent in metropolitan areas of the country. Additional ESMR systems are being built in allocations in the 900 MHz band. The 220 MHz band of 5,000 (and likely 10,000) channels are or will be available to construct ESMR-type systems that could compete for the ESMR market.

7.6.2.2 The ESMR industry is currently in the midst of change, converting to networked digital end-to-end technology. The user base is predicted to reach 4.2 million by 1999 including all of the various platforms. ESMR network operators are choosing technology which differs and is largely proprietary. Interoperable standards between ESMR providers are not necessarily being considered. There is currently no unit-to-unit interoperability between most ESMR systems and 800 MHz public safety systems. The ESMR feature set, with a strong emphasis on hand held radio operation, appears to have desirable public safety attributes. A single hand-held device operating over a wide integrated networked coverage area with data port, voice, fax and paging seems to align with public safety wireless needs. There are, however, major drawbacks with some of today's ESMR systems as they

relate to public safety use, particularly with respect to key voice attributes discussed previously.

7.6.2.3 Today's ESMR does not meet APCO's Project 16B[24] defacto functional trunking standard, a standard supported by all current public safety trunking system manufacturers. It does not support: (1) wireline control,[25] (2) simplex talk-around (direct unit-unit communications) at full power, (3) encryption, (4) dynamic regrouping, and (5) priority channel scan, all of which have been deemed essential for public safety systems. One need only examine the very basic requirements established by the public safety community to see the dichotomy between public safety systems and today's ESMR technology. Those requirements include graceful migration and interoperability: (1) there is no migration path between most ESMR technology and today's public safety technology, nor to any digital public safety systems currently proposed for tomorrow, (2) there is only a very limited interoperability potential between ESMR and public safety systems, and then only on 800 MHz General Category pool frequencies, not on 800 MHz public safety NPSPAC frequencies. An additional user concern is competitive procurement due to the limited number of ESMR manufacturers.

7.6.2.4 Regardless of the type of SMR/ESMR service, the public safety agency must insure that the coverage, security, priority access and reliability factors associated with each service provider/operator will meet the requirements of the applying agency. The degree of dependence on commercial access services by public safety wireless user will vary in accord with the commercial service providers specifications. The ESMR industry will advance to meet the demands of the mobile user and is intent on competing with cellular and the emerging PCS industry.

Reference:
"Public Safety Land Mobile vs. Enhanced SMR Systems" by John S. Powell, APCO Bulletin, pp 41-44, May 1995.

7.6.3 Dedicated Wireless Data Networks

7.6.3.1 Dedicated wireless data networks currently only offer data services (voice is excluded) in a wide cellular-like configuration serving subscribers with an air-time or flat-rate-based billing program for the transmission of information at rates varying between 8 kbps and 19.2 kbps. These services provide public safety

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24 The Associated Public Safety Communications Officer's (APCO) Project 16 was funded by the Law Enforcement Assistance Administration to develop a functional trunked radio standard for public safety use. This standard is met today by all manufacturers of public safety trunked radio systems.

25 Wireline control is essential because it allows a control point dispatching higher priority talkgroup(s) to instantly interrupt an in-progress transmission of a lower priority talkgroup when all voice channels are busy so that a transmission can be made without delay to the higher priority talkgroup(s).

an opportunity to access a dedicated wireless data network as a transport for mobile data systems.

7.7 Paging

7.7.1 Today, over 27 million people use commercial paging services. Continued use, and increased dependence are expected for many public safety functions. One benefit to public safety agencies is the ability to quickly alert and accurately deliver messages and instructions to specialized response teams from diverse groups or areas (SWAT, HazMat, SAR, etc.)

7.7.2 Early paging systems were limited primarily because of their one-way capability. Confirmation of delivery, acknowledgment, and message latency were all concerns that often precluded the use of commercial systems which could otherwise provide adequate service. Delays of several minutes are possible during busy periods. Missed messages are uncommon, but possible. Responses are not immediate, and these uncertainties exacerbate critical situations.

7.7.3 New higher speed, multi-level paging protocols have been developed to increase the efficiency of paging networks, while maintaining backward compatibility with existing (lower speed) devices. These protocols also improve pager battery life by synchronizing idle (pager sleep) times, and use message serialization to provide automatic detection and indication of lost messages. Finally, the protocols allow for acknowledgment of, and limited response to messages.

7.7.4 Systems have recently been introduced that utilize a high speed "forward"channel for the delivery of messages to paging receivers, and a lower speed, lower power "reverse" channel to send responses. The outbound channel has the ability to send fairly lengthy messages. In the commercial marketplace, typical outbound messages are limited to 500 characters. Host computer-based messages sent on a broadcast basis may range up to 1,000 characters in length. Although the reverse channel operates at lower speeds and at a lower power level in order to allow subscriber to carry very low power devices, delivery times on return messages are still measured in seconds. The return channel is utilized for several purposes. Two-way pagers provide for automatic acknowledgment that messages have been received by the device itself. In addition, freeform responses can be constructed with the use of a "mouse-like" button on newly available devices, and/or a choice of pre-canned responses can be sent ("yes","no","ETA<5 minutes", "ETA>5 minutes", etc.) from a remote location within the coverage footprint. In lieu of the pre-programmed responses stored in the device, a message originator can send a choice of responses from which the recipient can choose a reply along with the original message. Those responses override the preprogrammed responses stored in the device for that particular message.

7.7.5 With increased transmission speeds, higher content messages (such as facsimiles) can also be delivered to paging receivers with reasonable latency. Users of

two-way pagers may be alerted about a "large message", and be provided the option to receive it immediately, store it for retrieval at a more convenient time (by pager or through terminal access), or forward it to an alternate location (such as a preset E-mail address or facsimile number). If no acknowledgment of the alert message is received, the large message is not transmitted unnecessarily.

7.7.6 In wide area two-way paging systems, networks no longer have to send sequenced messages to alternate coverage areas once a page is acknowledged. Confirmation of delivery also reduces caller uncertainty, and should minimize multiple calls with the same message. Messages which aren't acknowledged may be held for retransmission (or confirmation of delivery) after the next successful page, or stored at the terminal for retrieval by other means. All of these methods improve message throughput and allow greater spectrum efficiency.

7.7.7 Advanced paging systems being introduced today allow peer-to-peer communications between pagers, by allowing the initiation of messages from pagers to the network over the reverse channel. Future two-way paging applications are likely to include services like AVL and individual-based GPS services, telemetry services, and interoperable services on dual devices with other wireless providers. These advanced paging systems would likely require connection of a paging device (such as an expansion card) into a personal digital assistant (palmtop computer). Such arrangements could also provide interfaces with existing computer networks to allow transaction processing (HazMat database access, urgent on scene inventory checks and supply/resource requests, etc.) These transactions will likely fit the same unbalanced profile (simple. low content requests, possibly based on menu retrieval and selection; with much larger responses). Information security, and the ability to transparently pass binary objects will become increasingly important as public safety use of these systems expands.

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Technology is constantly improving spectrum efficiency. Improvements in semiconductor processing and materials have resulted in roughly an order of magnitude advancement every five years. Rapid advancements in microprocessor technology has also been observed over the last two decades. Although theoretically possible to approach gains of 8:1 based on 25 kHz analog by the year 2010, it is appropriate to set the factor to 4:1 for planning purposes. A 4:1 efficiency recognizes the practical limit of advances over the intervening years; that is, doubling (2:1) in five years, doubling again in another five (4:1), then doubling again in five more years (for a 8:1 improvement in 15 years). Further, within current public safety bands, there will be an established base of equipment that will have to be amortized and withdrawn from service before full benefits of any advanced technologies can be realized. Additionally, many of the emerging public safety technologies (video and high speed data, for example) will require significantly wider bandwidths than the current 25 kHz channel for analog voice.

8.2 Digital technology will be the key technology for the future. A digital signal format is assumed by most of the bandwidth efficient methods employed today. Digital is essential to data transmission. Digital appears to be superior for secure communications technology. Nevertheless, there is a vast investment in existing analog voice communications technology which meets communications needs today and which will last for a long time. Analog equipment with 10 to 20 year lifetimes will continue to be installed for several years. Current public safety digital equipment offers approximately a 2:1 improvement in spectrum efficiency over 25 kHz analog. Consequently, the public safety community will operate with a mix of analog and digital equipment (a mix shifting towards digital) for the foreseeable future.

8.3 Trunking will become increasingly prevalent as the technology for trunking control becomes deployed and copied in what are currently known as conventional systems.

8.4 Improvement in technology unrelated to voice, such as data, will be driven by dramatic technology improvements in computers. It is quite conceivable that computer spectrum efficiency may be more important than voice spectrum efficiency in 2010. Imaging technology will be driven by improvements in digital signal processing (DSP) technology, which should also be dramatic in a decade.

8.5 Voice interoperability will require pre-planning. This is not a prediction, but rather a direct implication of the first two conclusions.

8.5.1 Spectrum efficient technology includes low bit-rate speech coding. Speech coding trends have already left the concept of "waveform coding" behind, where the ability to reproduce the exact analog speech waveform is lost. This property, employed commonly in land-line telephony where wire bandwidth is less of an issue, permits voice to be converted back and forth from analog to digital at will without loss of quality.

8.5.2 Low bit-rate speech coding also produces greater speech delay. This property is also not an issue in higher bit-rate waveform coding used in land-line telephony which permits voice to be converted back and forth from analog to digital without appreciable increase in delay.

8.5.3 Barring currently unexpected innovation in transcoding, this means that interoperability between systems with different speech coding technologies will likely suffer quality loss and increased speech delay, even when patched through infrastructure.

8.5.4 Direct interoperability over-the-air does not appear possible between systems with different speech coding technologies, bit rates, modulations, formats, access method, or any other attribute associated with the air-interface of a given RF system.