	County / Agency	POLICE 2010	VIDO-FLM PEN %	PERSNL PEN	FIRE 2010	VIDO-FLM PEN %	PERSNL PEN	EMS 2010	VIDO-FLM PEN %	PERSNL PEN	GOV SVCS 2010	VIDO-FLM PEN %	PERSNL PEN
NY	SUFFOLK	3,289	1.00%	33	14,204	1.00%	142	4,486	0.05%	2	3,981		0
NY	SULLIVAN	79	5.00%	4	4,740	30.00%	1,422	2,370	5.00%	119	928		0
NY	ULSTER	354	5.00%	18	7,084	30.00%	2,125	3,542	5.00%	177	1,505		0
NY	WEST-CHESTER	2,514	12.50%	314	7,182	1.00%	72	898	0.05%	0	2,267		0
NY	NY STATE POLICE	877	5.00%	44			0			0			0
NY	NY OTHER POLICE	250	5.00%	13			0			0			0
NY	NEW YORK CITY	37,562	12.50%	4,695	13,132	12.50%	1,642	3,054	10.00%	305	148,523	0.60%	891
	BRONX			0			0			0			0
	KINGS			0			0			0			0
	NEW YORK			0			0			0			0
	QUEENS			0			0			0			0
	RICHMOND			0			0			0			0
NY	METRO TRANSIT AUTH			0			0			0	48,861	1.00%	489
	METRO NORTH RR	200	5.00%	10			0			0	5,344	1.00%	53
	PORT AUTH NY NJ	700	12.50%	88			0			0			0
	LONG ISLAND RR	250	4.00%	10			0			0	1,950	1.00%	20
	NJ TRANSIT	150	1.00%	2			0			0	3,700	1.00%	37
	TOTALS	**83,229**		**10,191**	**153,321**		**29,958**	**51,909**		**1,829**	**251,138**		**1,490**
	PENETR. BY CATEGORY	**12.24%**			**19.54%**			**3.52%**			**0.59%**		

1. U.S. Bureau of the Census. *County and City Data Book: 1994.*

2. Prepared by Urbanomics, a consulting firm, for the New York Metropolitan Transportation Council, a planning organization of New York State government. The chart was last revised on 9/18/95.

3. New York State, Division of Criminal Justice Services, *1993 Crime and Justice Annual Report.*

4. State of New Jersey, Division of State Police, *Uniform Crime Reports, State of New Jersey, 1993.*

5. *Fire and EMS Data Book* is a compilation of detailed information on the resources available in the county of Nassau. The data included information on the number of personnel in each category.

6. *The 1994-95 Green Book* is an official directory of the City of New York.

7. Taken from *New York City Transit's Facts & Figures: 1995* booklet. Commodity Number 22-30-0202, Log Number 1095038, Printed 5/95.

ANNEX C - ADDITIONAL PUBLIC SERVICE OPERATIONAL REQUIREMENTS

1.0 Voice Requirements.

1.1 Dispatcher to Crews. This is a typical communications path between dispatchers and field personnel. The call types are typically business oriented with emphasis on operating the business in a safe and efficient manner.

1.2 Crew to Crew. This function relates to the typical communications between field users. These communications are used for the coordination of daily activities to maximize the safety and efficiency of operations.

1.3 Emergency Call. This function is typically initiated from a field user to a dispatcher. As the name implies, the call type is that of an emergency where loss of life or property is imminent or has already taken place.

1.4 "Talk Around". In many operations between field users, routing a call through the network or a repeater is not feasible for reasons such as access delay or being out of range of the system. A talk around mode is necessary so that the field users can communicate with each other, within the range of their mobiles and portables, without the assistance of a network or repeater.

1.5 Interconnect. In nearly all field activities, users have a need to communicate with people by way of land line telephones. Telephone interconnect is a necessary option for many of the present day radio systems.

2.0 Data Requirements.

2.1 End of Train Control. This is a system which provides a data communications link between the end of the train and the train crew. With this link, the engineer of the train can determine if the end of the train is in motion, what the brake line pressure is and whether the end of train flashing marker is illuminated. The engineer can also apply the brakes from the end of the train by remotely releasing the brake pipe pressure. All functions associated with this device relate to safer handling of the train.

2.2 Positive Train Control. This is a data system which utilizes a computer on board the locomotive to minimize collisions between trains. The locomotive computer obtains movement authorities from a host computer and calculates when it needs to stop the train based on the speed and weight of the train. If the limits of authority are going to be violated, the computer will stop the train automatically.

2.3 Track Warrants. Track warrants are the movement authorities which are used by the train engineer. Track warrants are typically read to the engineer over the radio system by the

dispatcher. There are plans in place to provide a data link between the dispatcher and the train engineer to reduce errors in copying the track warrant.

2.4 Crossing Safety. Crossing accidents are of great concern to the railroad industry. Systems are being investigated which will provide a notification to public safety vehicles and school busses that a train is approaching a specific crossing which may affect them. This will provide added warning of approaching trains.

In addition to the warning systems, data links are being investigated which will be used to report any malfunctions with the railroad crossing. Defects such as inoperative or broken crossing arms, vandalism, as well as power failures can be reported to maintenance personnel.

2.5 Cab Signals. Cab signals provide a visual warning to the train crew as to the status of the track immediately ahead of them. As an example, if the track is occupied, the signals to the train crew will show red. If the track is clear, the signals will show green. This form of alerting the crew is very helpful in train control and collision avoidance.

2.6 Train Line. The current form of braking for trains is through a pressurized brake line. If the air pressure is reduced, the brakes of the cars as well as the locomotives are applied. Often the air pressure does not respond as quickly or as fully as needed by the train engineer, creating a problem with train handling.

A train line is being developed which will provide a communications path thorough the train. One of the functions of the train line will be to provide electronic breaking information to each car, eliminating the need for the air line.

2.7 Consist Telemetry. An extension of the train line function listed above is a communications system which handles information for all items being transported. Typical information includes the condition of the cargo in terms of over temperature or rough riding which would be helpful when transporting hazardous materials. Other uses would be to provide additional alarming to the train crew for purposes of theft and vandalism control.

2.8 Facilities and System Protection Telemetry. The power utilities rely on communication links to assist in monitoring and control of power distribution systems. Very large and fast acting circuit breakers obtain information about short circuits and disconnect the power source in order to minimize risk of life and damage to property. These communication links are also utilized in the substations which are used to reduce the voltage of the transmission systems for distribution to households.

Pipe line companies transport a variety of materials which include water, oil , gas, and steam. Electronic monitoring and control systems are designed to assist the operators of these transport networks. If a malfunction occurs, the materials can be rerouted or their flow can be inhibited to minimize the impact to life, property, and the environment.

2.9 Load Shed Telemetry. On a smaller scale from system protection as described above, load shed telemetry is used to control the amount of power used by consumers. A data

communication system is used to remotely control air conditioners and electric water heaters in an attempt to minimize overloading of the transmission and distribution systems.

2.10 Defect Detector Communication Link. Defect detector communication is typically one way and is composed of a low power transmitter located at the detector sites. If a defect is detected, a synthesized voice radio transmission is sent. This will alert the crew of the train in the area of the detector before injury and/or damage occurs.

The following is a list of typical defect detectors:

1. Hot box/journal.
2. Dragging equipment.
3. High and wide equipment.
4. Rock slide/mud slide.
5. Flood.

2.11 Security System Monitoring. Property and equipment need to be monitored via security systems. Most of the applications require some form of wireless communications to establish the link.

2.12 Location Systems. For train control, location systems such as GPS are needed to obtain the location of the train in relation to limits of movement authority as well as other trains. Unfortunately, standard GPS does not have the required accuracy which can be accomplished by Differential Global Positioning Systems (DGPS). One of the requirements for the DGPS system is that the users must have a secondary data link which is independent of the satellite link.

2.13 Inventory Access. Both railroad and utility industries have situations where access to a store department record would facilitate derailment clean up or storm restoration respectively. To accomplish this, a data link between the field user and a host computer is necessary in order to determine and acquire needed materials.

3.0 Video Requirements.

Video Surveillance. As an extension of the security system monitoring item above, video surveillance provides much more information in specific situations than typical alarms can provide. In may cases, the video surveillance would be most effective if it was available through a wireless means.

4.0 Special Agents

Another application for communications in Public Services are those communications which occur between railroad police, also known as Special Agents, and local, state, as well as federal agents. The Special Agents have arrest authority if a crime occurs on the railroad right of way. They are often the first responders when dealing with murder, rape, robbery, drug enforcement, and vandalism just to name a few. These incidents require communications with other law enforcement agencies in order to coordinate operations.

Many of the railroads have a K-9 unit. The railroad police dogs are trained to assist the Special Agents in the same ways that Public Safety Police dogs are utilized. As an example, they are used to locate illegal drugs on railroad property. Once the suspected illegal materials are found, the Special Agents work with the local and federal and Department of Defense law enforcement agencies for further investigation and handling.

During derailments, the Special agents work with a variety of Public Safety entities to coordinate activities with the railroads in an effort to contain the disaster as quickly as possible. Most of the communications are voice, however, there is a significant need for data communications for the purposes of having access to the same information which is shared between the Police, Fire, and Rescue entities.

6.2 APPENDIX B - Technology Subcommittee Report

FINAL REPORT
of the
TECHNOLOGY SUBCOMMITTEE

PUBLIC SAFETY WIRELESS ADVISORY COMMITTEE

Sponsored by

FEDERAL COMMUNICATIONS COMMISSION
and
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

July 12, 1996

Technology Subcommittee Chairman: Alfred Mello
Alternate Chairman: Richard DeMello

Chair of TEC WG-1 (Matrix Preparation): Jeff Pegram
Chair of TEC WG-2 (Report Preparation): Steven Crowley
Technology Inventory: David Buchanan
Report Coordinator: Kathryn Hosford

Drafting Committee: Dave Buchanan, Thomas Christ, Richard Comroe, Steven Crowley, Al Davidson, Joe Gallelli, Ed Gilbert, Chuck Jackson, Art McDole, Susan Moore, Jeff Pegram, John Powell, Gregory Stone

---

THIS REPORT IS FOR DISCUSSION PURPOSES ONLY.

IT REPRESENTS THE VIEWS OF THE TECHNOLOGY SUBCOMMITTEE ONLY.

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED HEREWITHIN SHALL NOT BE USED IN WHOLE OR IN PART UNTIL FINAL ADOPTION BY THE FULL COMMITTEE OF THE PUBLIC SAFETY WIRELESS ADVISORY COMMITTEE.

THE FINAL REPORT OF THE TECHNOLOGY SUBCOMMITTEE MAY BE CHANGED BASED ON FURTHER DISCUSSIONS OF THE PUBLIC SAFETY WIRELESS ADVISORY COMMITTEE.

Comments regarding this Report may be submitted to:

Mr. Alfred Mello
Public Safety Communications Council
200 Metro Center Blvd. - Suite 6
Warwick, Rhode Island 02901
Phone: 401-738-2220
Fax: 401-738-7336

FINAL REPORT
TECHNOLOGY SUBCOMMITTEE
PUBLIC SAFETY WIRELESS ADVISORY COMMITTEE

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY
2.0 INTRODUCTION AND OVERVIEW
3.0 REVIEW OF TECHNOLOGY SUBCOMMITTEE PROCESS
- 3.1 Background
- 3.2 Presentations
- 3.3 Matrix/Inventory

4.0 PUBLIC SAFETY COMMUNICATIONS APPLICATIONS
- 4.1 Background
- 4.2 Voice
- 4.3 Data
- 4.4 Image
- 4.5 Video
- 4.6 Location Information/GIS/APL/AVL

5.0 EXISTING PUBLIC SAFETY COMMUNICATIONS CAPABILITIES
- 5.1 Background
- 5.2 Voice
- 5.3 Data
- 5.4 Image
- 5.5 Video

6.0 SYSTEM BUILDING BLOCKS AND TOOLS: FUNDAMENTAL CONSTRAINTS AND LIKELY EVOLUTION
- 6.1 Background
- 6.2 Digital Integrated Circuits
- 6.3 RF Generation Devices
- 6.4 Source Coding
- 6.5 Modulation
- 6.6 Multiple Access Techniques
- 6.7 Error Correction Coding
- 6.8 Constraints on Using Various Bands
- 6.9 Backbone System Elements
- 6.10 Performance Modeling and Verification

7.0 COMMERCIAL SERVICES — TECHNOLOGICAL CAPABILITIES AND DEVELOPMENTS
- 7.1 Background
- 7.2 Mobile Satellite Systems
- 7.3 Cellular Telephone Systems
- 7.4 Cellular Digital Packet Data (CDPD)
- 7.5 Personal Communications Services (PCS)

7.6 SMR/ESMR
7.7 Paging
8.0 CONCLUSIONS AND RECOMMENDATIONS

APPENDIX A — SUMMARY OF TECHNICAL PRESENTATIONS
APPENDIX B — TECHNOLOGY INVENTORY SUMMARY
APPENDIX C — TECHNICAL PARAMETERS FOR FORECASTING SPECTRUM DEMAND

FINAL REPORT
TECHNOLOGY SUBCOMMITTEE
PUBLIC SAFETY WIRELESS ADVISORY COMMITTEE

1.0 EXECUTIVE SUMMARY

1.1 Background

1.1.1 Wireless communications, mobile and portable, provide an essential resource for public safety operations. This paper describes the technology used today in public safety radio and the technology reasonably expected to be available by the year 2010 to support public safety mobile communications. This information is to be used to support forecasts of spectrum demand.

1.1.2 The revolution in microelectronics and computers has brought and will continue to bring enormous improvements in the performance of these systems. Improved electronic systems also change the ways public safety agencies can use wireless communications systems. There was no need for wireless access to digital messaging systems until digital messaging systems came into being. While voice communications has been, and remains today, by far the most important public safety application of wireless technology, it appears highly likely that non-voice communications, most importantly data and image communications, will become increasingly important and will account for a major fraction of all public safety wireless communications by the year 2010.

1.1.3 The Technology Subcommittee is tasked with the responsibility of reviewing present technologies used by public safety. It is also to identify spectrally-efficient existing and emerging technologies that will impact spectrum requirements. As part of the technology deliberations, 19 organizations made presentations highlighting wireless technologies pertinent to public safety activities. The Subcommittee also undertook to compile an inventory of current, under development and future technologies.

1.1.4 This report provides a self-contained description of wireless technology and trends in wireless technology that appear to be most important for public safety communications. This report also gives the reader with an up-to-date (mid-1996) view of the evolving technologies that support wireless communications and with forecasts of the evolution of those technologies. The report provides the technical information necessary for predicting, in conjunction with usage forecasts, the future spectrum requirements of public safety land mobile radio.

1.1.5 The following table provides a simplified snapshot of the state of public safety communications technology relative to voice, data, image, and video.

	DESCRIPTION
Voice	Public safety systems are designed to maximize availability and minimize delay. Current systems are 25 kHz analog. Future is digital. Digital systems are being introduced. Digital improves security and supports data.
Data	Data today is typically sent over the voice channel or by a separate radio. Data rates range from 0.3 to 19.2 kbps in a 25 kHz channel. Mobile data terminals (MDTs) are growing rapidly.
Image	Current systems can support still images but are little used today. Outlines existing standards for facsimile and snapshots. Medical services will need high resolution imaging.
Video	Today's systems are wideband, analog and are not widely deployed due to lack of allocated spectrum (one channel, shared with television services). Digital video cameras are being introduced.

1.2 Public Safety Communications Applications

1.2.1 Increasingly, voice is transitioning to digital transmission. High quality digital speech in land mobile channel bandwidths could not be implemented in affordable technology until recently. Digital transmission provides mechanisms to combat the familiar static and pop effects that radio reception impairments traditionally caused to analog transmission. Digital signals can be encrypted to prevent interception far more easily, reliably and effectively than can analog signals. Among the attributes of voice communications systems are availability and delay.

1.2.2 With the growth in the use of computers and associated reductions in the cost of computing equipment has come an increased demand for data communications capabilities. Many of the early public safety data communications systems used circuitry much like telephone modems to create a voice-like signal which could both carry the data and travel over the analog voice paths of the public safety radio communication systems. Such hybrid systems are still widely used today.

1.2.3 More recently, manufacturers have begun to provide radio systems that are fully digital and that can carry data directly on the radio channel. Transmitting high speed data reliably on mobile radio channels is an enormous engineering challenge as compared to transmitting via wire, cable, microwave, fiber optics or other similar carriers. Key attributes of data communications systems are message/file size, reliability, error control, and encryption.

1.2.4 Images represent a special category of data that is a numeric representation of a picture. The rapid increase in use of "wire-line" based facsimile transmission and

similar image technologies within the public safety services has paralleled that within the broader economy.

1.2.5 There are several public safety imaging applications. Emergency medical providers desire the ability to transmit images of the injured from paramedic units back to trauma centers or hospitals to aid in diagnosis and pre-arrival treatment. Fire agencies desire the ability to transmit building plans and copies of permit and other data for fire prevention and protection. Law enforcement agencies need to quickly transmit fingerprints from field units back to local, state and federal databases; units need the capability to receive mugshots and drivers license photographs to aid in identifying people in the field. Key attributes of image communications systems include resolution, B/W vs color, compression, and error control.

1.2.6 Wireless video systems have seen limited use in state/local public safety services to date primarily due to a lack of available public safety spectrum over which to implement these systems. Key attributes of video communications systems include frame rate, resolution and color level, error control, and compression.

1.2.7 The fire service uses full motion video extensively in some areas, primarily to monitor wildland fire scenes from airborne platforms, providing real-time video back to emergency command centers. Law enforcement agencies, particularly at the federal level and which have spectrum available for video, have long used video for surveillance purposes. State/local agencies have only recently begun to implement similar systems for monitoring areas of high crime and drug use. State/local transportation agencies have implemented wireless video systems to monitor traffic flow and detect collisions and hazards on roadways in congested metropolitan areas.

1.2.8 There is a growing need for full motion video for use with robotic devices in bomb, hostage, hazard avoidance and hazardous materials situations.

1.2.9 Public safety agencies have struggled with the problem of identifying the location of vehicles and personnel. Today there are several ways to obtain such location information. Each alternative has its strengths and weaknesses.

1.3 Existing Public Safety Communications Capabilities

1.3.1 Most public safety communications systems use analog FM technology operating in 25 or 30 kHz channels to carry their voice signals. Public safety communications systems normally operate using a variant of one of two basic methods: repeater and trunked.

1.3.2 While digital voice is a technological possibility, it is little used today in public safety communications. It is expected that digital voice systems will be offered by several manufacturers in the public safety market in the next few years.

1.3.3 Today data communications capabilities are used in public safety for such purposes as digital dispatch and checking computer data bases for information associated with wanted persons/property and vehicle registration license plates.

1.3.4 Still images include snapshots such as accidents, and crime scenes, mug shots, fingerprints, and a wide variety of other images. Today, there is relatively little use of still image transmission to and from the field in public safety. It is expected that such systems will be deployed in increasing numbers over the next decade and a half.

1.3.5 Video is used in public safety today primarily for surveillance of crime scenes and of highways. Transmission of such images back to central locations could be quite helpful in the management of major incidents. Today, video images are normally transmitted using analog modulation. Wideband channels (several megahertz) are normally used to carry full-motion, high-quality video. However, only very limited spectrum is available to state and local. In the future, we expect that most public safety video communications will be digital. Currently, though, compression equipment is still expensive and standards are changing rapidly. The coming of affordable digital video cameras and affordable digital compression can be expected to lead to substantial growth in the requirements for public safety video communications.

1.4 System Building Blocks and Tool: Fundamental Constraints and Likely Evolution

1.4.1 The fundamental technology thrust through the year 2010 will be, as it has been in the recent past, that of semiconductor technology. The improvements in semiconductor processing and materials have resulted in roughly an order of magnitude advance every five years. Rapid advancement is also observed in the progress of microprocessor technology over the last two decades.

1.4.2 The batteries required to operate portable communications equipment are usually heavy, provide limited hours of operation, and can be expensive. A number of developments in battery technology are alleviating this situation.

1.4.3 Spectrum efficiency is improved if more communication channels can be placed within a given band of spectrum. In the past, the ability to decrease the channel size has been limited by both the transmission bandwidth and frequency stability concerns. Frequency stability in land mobile radio has also benefitted from improvements in semiconductors. Improvements in frequency stability can be used to enhance spectrum efficiency even when channel spacing is not reduced because the guard bands around the occupied bandwidth of each transmission can be reduced. The information content of the transmitted signal can be increased while maintaining acceptable adjacent channel splatter. This is important because reductions in guard bandwidth are limited by adjacent channel splatter considerations.

1.4.4 Smart antennas is a term applied to a family of technologies that generally integrate active antenna elements with microprocessor technology. By changing the current distribution of the array, the shape of the beam can be changed electronically in real-time.

1.4.5 Diversity is a commonly used technique for improving the quality of both digital and analog signals. When the new technique of single sideband is employed the use of multiple antennas becomes a virtual necessity, as when the vehicle is traveling at high speed, signal will become distorted due to phase shift. The most common form of diversity is space diversity, which is implemented using two appropriately spaced antennas. Another method being researched is a one-piece diversity antenna system that uses two antenna elements that performs the signal combining function in the antenna base. Maximal ratio diversity combining is a third diversity technique which is used to combat fading. The advantages of these techniques must be weighed against the disadvantages.

1.4.6 Using today's systems, additional traffic demands can only be met by increases in the available spectrum. However, the demands can, at least in part, be offset by utilizing semiconductor advances to make more efficient use of the limited spectrum resources. Information compression allows reduction in the amount of information which must be transmitted on the communications channel. Digital speech encoding has received significant attention of late. This means of transmitting speech leads naturally to encryption which is one very important aspect in many public safety communications scenarios. Looking to the future, it can be expected that increasingly powerful digital signal processing IC's will facilitate the introduction of more powerful and effective methods for reducing the amount of information that must be transmitted on the communication channel.

1.4.7 As digital processing capability improves, higher complexity compression algorithms will become viable, increasing the compression ratios possible for these services. Thus, by the year 2010, compression schemes more than ten times as complex as those of today should be viable for public safety radio. As a result, an assumption of a 3:1 increase in source coding efficiency for fax by 2010 seems reasonable.

1.4.8 For full-motion video, a 2:1 improvement over today's compression ratios, or roughly 0.25 bits/pel, should be achievable by the year 2010. For slow video, a 3:1 increase in slow video coding efficiency is indicated when we it is assumed that MPEG-4 will be implemented by 2010.

1.4.9 Another method of improving improved spectrum efficiency is to increase the amount of information that the communication channel can support. Nonlinear constant-envelope systems have approached 1.28 bit/sec/Hz, considered to be the limit for those systems. Linear modulation, based on newer SSB-based techniques, is expected to be able to improve this efficiency to approximately 5 bit/sec/Hz by the year 2010; while such linear modulation narrowband techniques have long been

used in other applications, the engineering challenges of matching them to mobile communications channels have only recently been overcome in commercially available products.

1.4.10 FDMA, TDMA, CDMA, and TDD are different channel access methods. In FDMA (Frequency Division Multiple Access), different conversations are separated onto different frequencies. In TDMA (Time Division Multiple Access), different conversations are separated into different time slots. In CDMA (Code Division Multiple Access), all conversations are separated by code space. And in TDD (Time Division Duplexing multiple access), a single channel is shared in time to achieve full duplex operation. Each has specific strengths and weaknesses.

1.4.11 Software programmable radios, in which applications are configured under software control, makes it possible to implement multiple military, law enforcement, and commercial air interface standards 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. There are many challenges, however, to producing a practical and economical software programmable radio for law enforcement applications; software radios are now much more expensive that hardware-based radios, with the market being largely confined to military applications. 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.

1.4.12 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. It is expected that the future supply of backbone system elements will 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. 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. 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.

1.4.13 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. 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. The Telecommunications Industries Association TR-8 WG-8.8 Technology Compatibility Committee is working under a charter and mission statement to address these technical challenges.

1.5 Commercial Services — Technological Capabilities and Developments

1.5.1 Many present and future technological capabilities are (or will be) developed for large commercial service providers or government systems. 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.

1.5.2 Satellite systems support thousands of voice channels and in many spot beams are used so that some frequency reuse is possible. Satellite services can be completely digital thereby facilitating 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. Priority designations will be lost when communications enter the Public Switched Telephone Network (PSTN) as they are currently configured unless dedicated lines are provided between gateway stations and public service agencies.

1.5.3 Current cellular telephone systems have several attributes which limit their appeal to public safety users. They are designed to provide adequate capacity during most peak periods, but they are still vulnerable to overload and abuse during large incidents or special activities. In spite of these limitations, cellular telephones are able to meet certain aspects of public safety communications needs. They are useful for communications between public safety field personnel and the public being served. 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.

1.5.4 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 hand-offs between cell sites are often imperceptible during voice conversations, but most data communications equipment sends (and expects to receive) a continuous

carrier signal. 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. 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.

1.5.5 Personal Communications Systems (PCS) are an emerging commercial technology. 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. 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. 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.

1.5.6 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 systems are characterized by a single high-power, high-elevation base station for maximum coverage. 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.

1.5.7 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. 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.

1.5.8 Today, over 27 million people use commercial paging services. Continued use, and increased dependence are expected for many public safety functions. 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. With increased transmission speeds, higher content messages (such as facsimiles) can also be delivered to paging receivers with reasonable latency. 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.

1.6 Conclusions and Recommendations

1.6.1 In the year 2010, a great deal of available resources will be served by some technology which has not yet even emerged from the research labs. However, several aspects of future technology are fairly well agreed by examination of technical trends, regardless of whatever specific technology may emerge within the next decade.

1.6.2 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.

1.6.3 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.

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

1.6.5 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.

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

1.6.7 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. Low bit-rate speech coding also produces greater speech delay. 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.

1.6.8 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.

1.6.9 Without any significant coordination, disparate systems will achieve analog interoperability using a common base-line interoperability technology.[1] This can serve both analog speech or data that is converted to a speech bandwidth signal in a fashion similar to using modems over telephone. Data transmitted via analog transmission are subject to no more coordination than generally practiced today requiring compatible modems on both sides of a telephone link. Data speed is significantly less than compared to direct digital transmission.

2.0 INTRODUCTION AND OVERVIEW

2.1 This paper describes the technology used today in public safety radio and the technology reasonably expected to be available by the year 2010 to support public safety mobile communications in order to develop technical support for forecasting spectrum demand.

2.2 This paper proceeds in four steps. First, we describe the communications services needed by public safety and the demands they make for communications support. Second, we describe the current state and likely evolution of the key technologies used to build communications systems. Next, we describe the rate of advance of these key technologies and offer predictions on the capabilities of future

[1] We note that the PSWAC Interoperability Subcommittee has recommended such a common transmission mode (analog FM) for such interoperability. We note that current generation digital cellular telephones also support FM transmission mode.

communications systems. Finally, we review commercial technologies to refine our picture of future wireless capabilities.

2.3 What will be the predominant technology of the year 2010? In the year 2010, a great deal of available resources will be served by some technology which has not yet even emerged from the research labs. Remember that the first trunking systems were only deployed in the very late 70s, and the first cellular systems went commercially on-line in the early 80s. The most pervasive technology of the year 2010 may be just emerging, or may still be yet to emerge. We just don't know. For certain, the cutting edge technologies of today will still be employed for 15 years. However, several aspects of future technology are fairly well agreed by examination of technical trends, regardless of whatever specific technology may emerge within the next decade.

3.0 REVIEW OF TECHNOLOGY SUBCOMMITTEE PROCESS

3.1 Background

3.1.1 The Omnibus Budget Reconciliation Act of 1993 required the Federal Communications Commission (FCC) to study public safety spectrum needs through the year 2010. The 1995 FCC Public Safety Report identified public safety issues needing to be defined, studied, and clarified to determine the scope of the public safety community spectrum needs. Subsequently, the FCC and the National Telecommunications and Information Administration (NTIA) established the Public Safety Wireless Advisory Committee (PSWAC) to address public safety requirements through the year 2010.

3.1.2 Five subcommittees were established to accomplish specified tasks. The five subcommittee are: Operational Requirements, Technology, Interoperability, Spectrum Requirements, and Transition. The Technology Subcommittee is tasked with the responsibility of reviewing present technologies used by public safety. It is also to identify spectral efficient, perspective and emerging technologies that will impact on spectrum requirements. In developing this report, the Technology Subcommittee has cataloged public safety equipment, both present and developmental, solicited input about a wide range of mobile systems including commercial providers, and reviewed several white papers.

3.2 Presentations

3.2.1 As part of the technology deliberations, 19 organizations made presentations highlighting wireless technologies pertinent to public safety activities.[2] The

[2] A summary of the oral presentations are included with this report as Appendix A. Written submissions can be found in the PSWAC public inspections file WTB-1 at the FCC's Wireless Telecommunications Bureau.

presenting organizations fell into three groups: manufacturers, commercial service providers, companies engaged in research and development, and users, some of which have developed their own custom communications systems. The following gives an overview of the concepts presented.

3.2.2 Presentations consisted of several manufacturers of traditional land mobile radio systems denoting the latest in current technologies for public safety use. The Subcommittee also heard details of a proposed mathematical model to be used in projecting public safety spectrum requirements; this model is being considered by the Spectrum Subcommittee. The Subcommittee also heard from several commercial service providers active in cellular, satellite, paging and messaging, and communications systems integration and networking. Among their respective views is the importance of interoperability and the role that commercial systems can play in public safety communications.

3.2.3 Several technology advancements were described, including those related to trunking, modulation, multiple access, voice coding, and antennas; a common theme is that these advancements will continue to reduce the bandwidth necessary for sending a given quantity of information. Satellite service was presented as a form of backup in emergencies if terrestrial systems are destroyed or overloaded, as well as useful in remote areas where it is not economical to deploy terrestrial facilities. Cellular service providers said their services can be used to support emergency needs as well as to support administrative uses. One system has been employed in disaster and civilian crowd control applications to support inter-agency communications. Some of the commercial wireless services have fleet-calling capability, which can be used to efficiently communicate with a large number of users. The trend in these systems is toward increasing use of digital technology, which provides increased security over analog systems.

3.2.4 Public safety users made presentations not only in their user capacity, but also as developers of innovative systems that perform public safety communication functions. A full motion video surveillance system was described, which is used as an aid to a narcotics law enforcement program. The system is assembled from a variety of existing, new, and even homemade components. Despite this resourcefulness, the systems deployment is hampered because only one frequency (2.475 GHz) is available for puolic safety wideband video use; moreover, the frequency must be shared with many more broadcasters who use it for new gathering purposes.

3.2.5 A microwave system custom-made from surplus components is used in emergency situations as a wireless link in the local loop. It is deployed at a command center at a disaster scene to provide seamless interconnections with the public switch telephone network. The system is mounted on a van that can be moved as the command center relocates. Put to use in the 1991 Oakland, California fire, the system helps overcome time-to-deploy, traffic saturation, and reliability problems

that can occur with other communications systems, such as cellular telephone and hard-wired PSTN interconnections.

3.2.6 A satellite system was described that is used to form a network among many California public safety agencies. Another public safety user who, though not a technology expert, reviewed the barriers experienced in the use of technology, especially with regard to interoperability. Several real-world examples of communications problems in disaster situations also were presented.

3.3 Matrix/Inventory

3.3.1 The Subcommittee also undertook to compile an inventory of current, under development and future technologies that will impact spectrum usage over the next 15 years. The subcommittee developed a matrix form to use to gather the information. Requests for inventory information were sent to 25 companies who have participated in the meetings or were known to the Subcommittee. Six companies responded with information on fifteen technologies.[3]

3.3.2 The technologies reported by the companies cover current and systems under development. No future technologies were reported by the responding companies. For current technology, Motorola and Transcrypt indicated systems are available or under development using FDMA for 12.5 kHz bandwidth. Also under development from Ericsson is a TDMA system that will use 6.25 kHz bandwidth (2 channels in 12.5 kHz). Another TDMA system was Motorola's iDEN system which is used commercially and has a 4.167 kHz bandwidth efficiency. Although these technologies appear to target primarily voice, most also support some level of data capability. There were no responses that reported data only or video systems; although one indicated that it could support video and snapshot on its TDMA system. Except as noted above, no responses were received for commercially provided technologies such as mobile satellite systems.

4.0 PUBLIC SAFETY COMMUNICATIONS APPLICATIONS

4.1 Background

4.1.1 Public safety pioneered mobile radio communications. The dramatic improvements in safety and productivity that came from putting radios in police patrol cars and fire engines led public safety agencies to deploy radio systems long before such radio systems where used in the broader economy. Public safety radio communications began with group voice dispatch as the sole radio service. This breadth of utilized radio services has grown significantly with more new services anticipated to come. This section will introduce and describe distinct radio services.

---

[3] See Appendix B for a summary of information received.

4.2 Voice

4.2.1 Speech is the most fundamental means of human communication and thus it is only natural that public safety radio systems provided voice communications first. While transmission of the spoken word is fundamental, radio systems often go beyond simple transmission of the words to provide other information such as inflection, emphasis, ability to recognize the speaker, and so on.

4.2.2 Originally, all mobile radio systems used analog transmission and the voice signal was transmitted as an analog waveform. Such transmissions were normally restricted to the frequency range of 300 to 3,000 Hz about the same as on telephone calls. This range of speech frequencies provides reasonable speech quality without using excessive spectrum. At present, the most commonly used analog transmission technology is frequency modulation (FM) in a 25 kHz bandwidth. The bandwidth expansion of FM serves to help protect the voice signal from noise and interference. Analog FM signals can be received easily on hobby-type "scanners". This has both positive and negative effects. Criminals can eavesdrop on public safety communications. But, low cost scanners are also widely used by public safety agencies to monitor the radio communications of other agencies to provide assistance. Scanners provide one of the most widely used forms of interoperability. While historically, analog transmissions were difficult to encode in a manner that provided a high degree of transmission security from monitoring by unintended and/or unauthorized listeners, modern signal processing chips allow for far stronger analog scrambling. The process of scrambling or rendering transmissions unintelligible except to authorized listeners is known as "encryption" and is very clearly defined and controlled at different levels of protection by the National Security Agency (NSA) and the National Institute of Standards and Technology (NIST).

4.2.3 Analog mobile radio has often been employed as a carrier for equivalent voice band signals other than voice. Its use as an analog carrier for traditional voice modems is described later in this report. Numerous other uses for voice-band analog signaling include everything from coded sequential tone squelch, to touch-tone signaling such as from a telephone keypad (known as dual-tone-multi-frequency, or DTMF).

4.2.4 Increasingly, voice is transitioning to digital transmission. In the digital service the speaker's analog voice waveform is converted to a numeric representation before transmission. After reception the received numeric representation is converted back into an analog waveform for presentation to listening users. The device used to convert the analog voice waveform to a numeric representation is called a vocoder, which is shorthand for VOice CODER. Speech quality varies among different vocoders. Typically, those that transmit more digital bits generally produce better speech quality. High quality digital speech in land mobile channel bandwidths could not be implemented in affordable technology until recently.

4.2.5 Digital transmission provides mechanisms to combat the familiar static and pop effects that radio reception impairments traditionally caused to analog transmission. The ability to mitigate the effects of errors without resulting in distracting audible effects has a significant impact on improving the perceived quality. This is usually accomplished by moderately increasing transmission overhead, although further increased overhead may result in the requirement for increased bit rate and wider bandwidths.

4.2.6 One advantage of digital voice transmission is security. Digital signals can be encrypted to prevent interception far more easily, reliably and effectively than can analog signals.

4.2.7 A few key attributes of voice communications systems include:

4.2.7.1 *Availability*. Availability of communications to public safety professionals for local to cross-jurisdictional needs is critical, with lives (of both citizens and officers) and property at stake. This manifests itself in the highest requirements for availability. Availability is generally descriptive of the percent of time that a radio channel is available for use when needed.

4.2.7.2 *Delay*. Timeliness of communications is critical, with lives and property often at stake. The classic example of latency is the fact that it takes less than a second to utter the entire phrase "don't shoot." Within the phrase, the first word "don't" takes only a fraction of a second, with obvious effect on the meaning of the phrase. Delay is generally descriptive of (1) the time between when a radio channel is needed to when it is available, (2) the lag between when it is available to when it can begin serving useful communications, as well as (3) the start-up character of the service. For the purposes of this report, the following terms (which are variously interpreted today) are presented:

4.2.7.2.1 Set-up. The time necessary to make a channel available for service. The time waiting for a busy channel to become available is not included.

4.2.7.2.2 Busy. The time waiting for a busy channel to become available in trunking systems. This is typically expressed as the average waiting time for only those occurrences where a busy condition occurred.

4.2.7.2.3 Truncation. The amount of speech lost between when a voice service is requested to when it is set-up and conveying speech. Digital technology may trade-off truncation for latency.

4.2.7.2.4 Latency. In-to-out delay for an established channel. While analog was real-time, digital processing, transmission, blocking, vocoding, and other factors can produce higher latency.

4.2.7.3 *Clarity*. The ability to recognize the individual speaking.